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SYSTEMS STUDY OF AIR POLLUTION FROM MUNICIPAL INCINERATION

A Report to

THE DIVISION OF PROCESS CONTROL ENGINEERING
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

UNDER CONTRACT CPA-22-69-23

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SYSTEMS STUDY OF
AIR POLLUTION FROM
MUNICIPAL INCINERATION

U.S. Dept. of Health, Education and Welfare
National Air Pollution Control Administration

VOLUME II

(Appendices)

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APPENDIX A

SIZE REDUCTION COSTS

APPENDIX A

SIZE REDUCTION COSTS

A number of incineration concepts, especially those involving fluid bed or suspension burning, require refuse size reduction. An analysis was made of recent data collected by Battelle Memorial Institute under contract with the Bureau of Solid Waste Management,* and generalized cost curves were prepared permitting estimates of capital and operating costs for this operation.

In the Battelle study, costs were collected for 21 different shredding installations. In order to increase the size of the data bank, the study included systems producing a variety of product sizes and systems used for a variety of different feed materials. To bring these diverse data to a common basis, input material factors and product size factors were developed to modify equipment capacities and energy consumption estimates provided by the manufacturers. The input material factors were derived by averaging the horsepower-per-ton values for each of several feed materials and relating them to a value of 1.00 for municipal solid waste:

Feed Material	Horsepower-per-Ton Factor
Selected municipal solid waste	1.00
Sorted municipal solid waste	0.65
Wood (or fibers) only	0.43
Automobile bodies	2.82

As the product size is an important consideration in size reduction operations, factors were also necessary to adjust for the differing product top-size for the equipment studied. These factors were adjusted relative to 1.00 for a 6″ product size, as follows:

Product Top-Size	Product Top-Size Factor
6″ square pieces	1.00
4″ square pieces	1.39
2″ square pieces	1.64 (2.00 is suggested -
1″ square pieces	2.38 see below)

** Recovery and Utilization of Municipal Solid Waste, A Summary of Available Cost and Performance Characteristics of Unit Processes and Systems,* Report to the Solid Waste Program, USDHEW; Battelle Memorial Institute, November 1968.

In evaluating the power-use factor correlation regarding product top-size, a number of different graphical correlations were tried. This was necessary to provide a basis for extrapolation to 1/2" top-size. The best correlation (Figure A-1) indicated that the factor assumed for 2" top-size may be in error as it is inconsistent with the relationships among the other data. As a result, a power-use factor of 2.00 was used for the 2" product top-size in our analysis.

The capital investment required for a size reduction mill (for 6" top-size) is shown in Figure A-2. Costs for different top-sizes can be computed by multiplying the top-size factors shown above by the mill capacity desired; e.g., producing 100 tons/hr at 1" top-size requires a mill which produces 267 tons/hr at a 6" top-size. This plot is taken directly from the Battelle report with only a slight adjustment to a 1969 dollar base. These costs apply only to the shredding equipment and exclude foundations, installation costs, conveyors, etc.

In evaluating the total operating cost, the Battelle data were reviewed, and it was found that all vendors had estimated that approximately one man would be fully committed to the mill operation. As a result, in our evaluation of capital investment, we assumed a labor assessment of one man-hour/hr of shredding facility operation.

To correlate the reported maintenance cost estimates (in dollars per machine-hour vs. mill capacity), the data were adjusted by the power-input factors presented above to correct for top-size and material factors. This adjustment was made because it was felt that maintenance costs should generally be a direct reflection of the energy expended within the machine. The adjusted data fall in the fairly narrow band shown in Figure A-3. It can be seen from this correlation that the maintenance cost is directly proportional to the tons processed; and, in fact, the cost in dollars/ton is relatively constant over the wide range indicated ($0.345/ton at 6" top-size).

Total capital and operating costs were calculated for several different product sizes and incinerator plant capacities. It was assumed that twin milling units were needed for reliability. It was also assumed that the shredding operation would be for one shift per day only. To compensate for the fact that the machines would not always be operated at their rated capacities, a one-third safety factor on installed capacity was provided (i.e., active mill production was calculated at 3/4 of rated capacity).

Capital charges were allotted assuming amortization of machine costs over fifteen years and an average interest rate of 3% per year. The total capital investment was calculated from the bare equipment costs shown in Figure A-2, multiplied by 2.4 to account for field installations, indirect charges, and a 10% engineering fee and contingency. Note that the capital investment must be modified to account for product top-size effects.

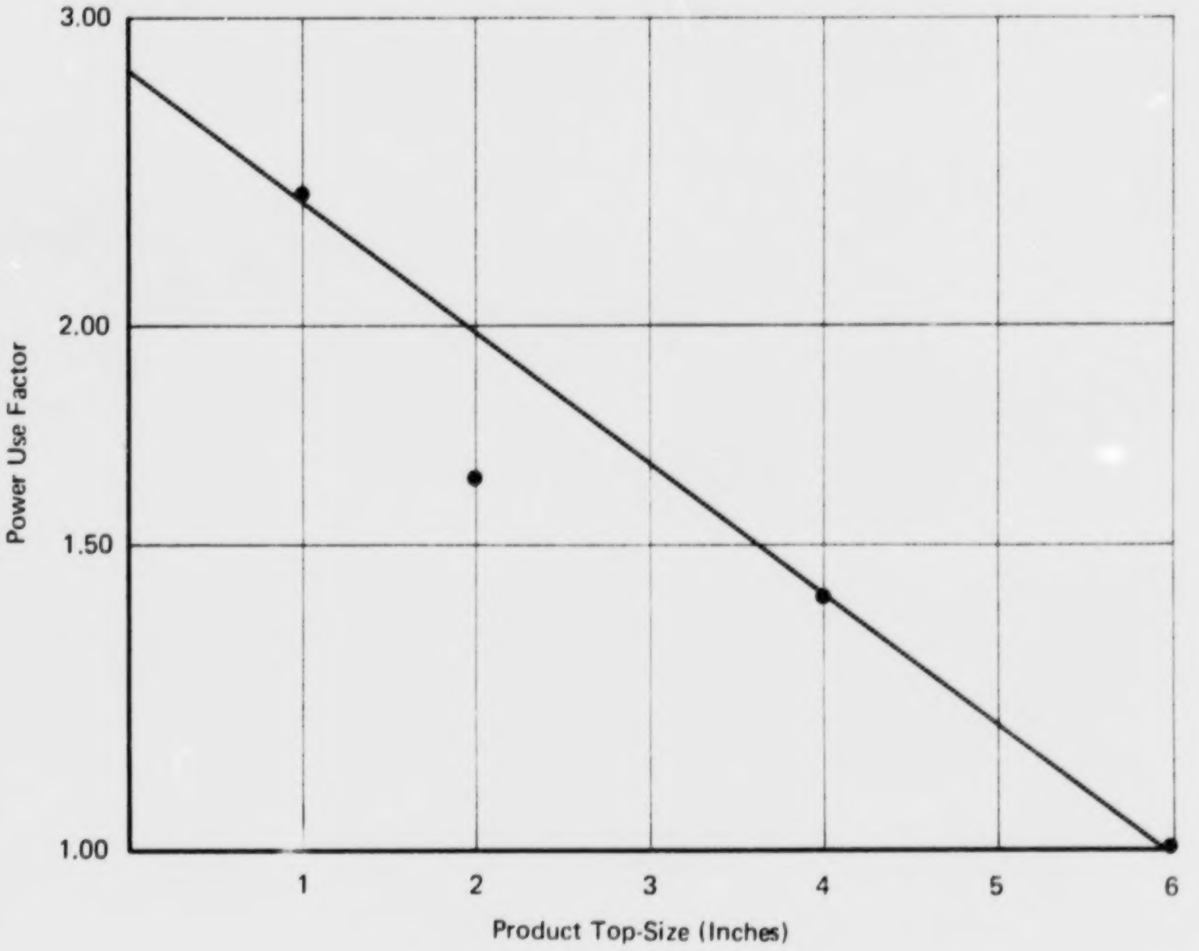


FIGURE A–1 POWER USE FACTOR CORRELATION

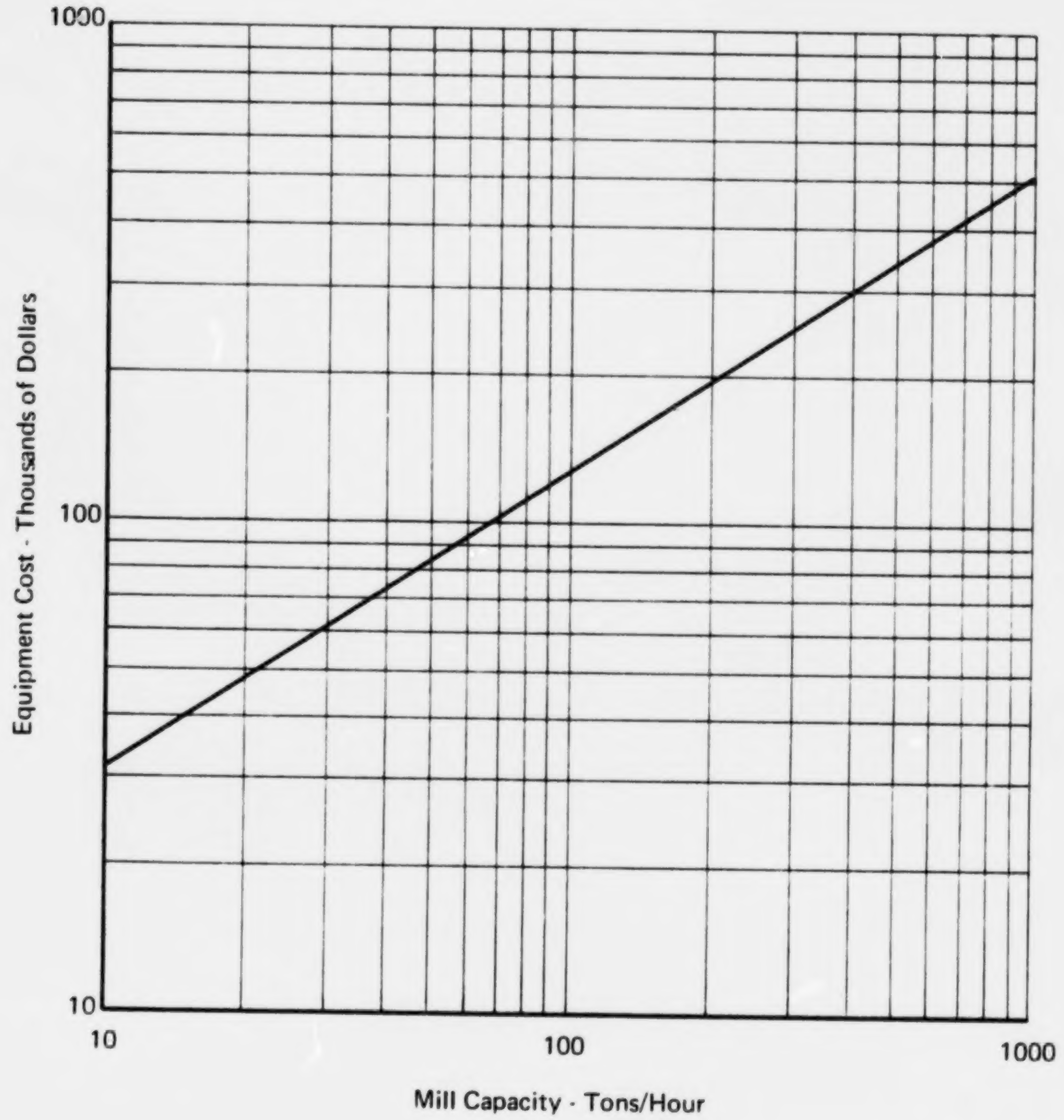
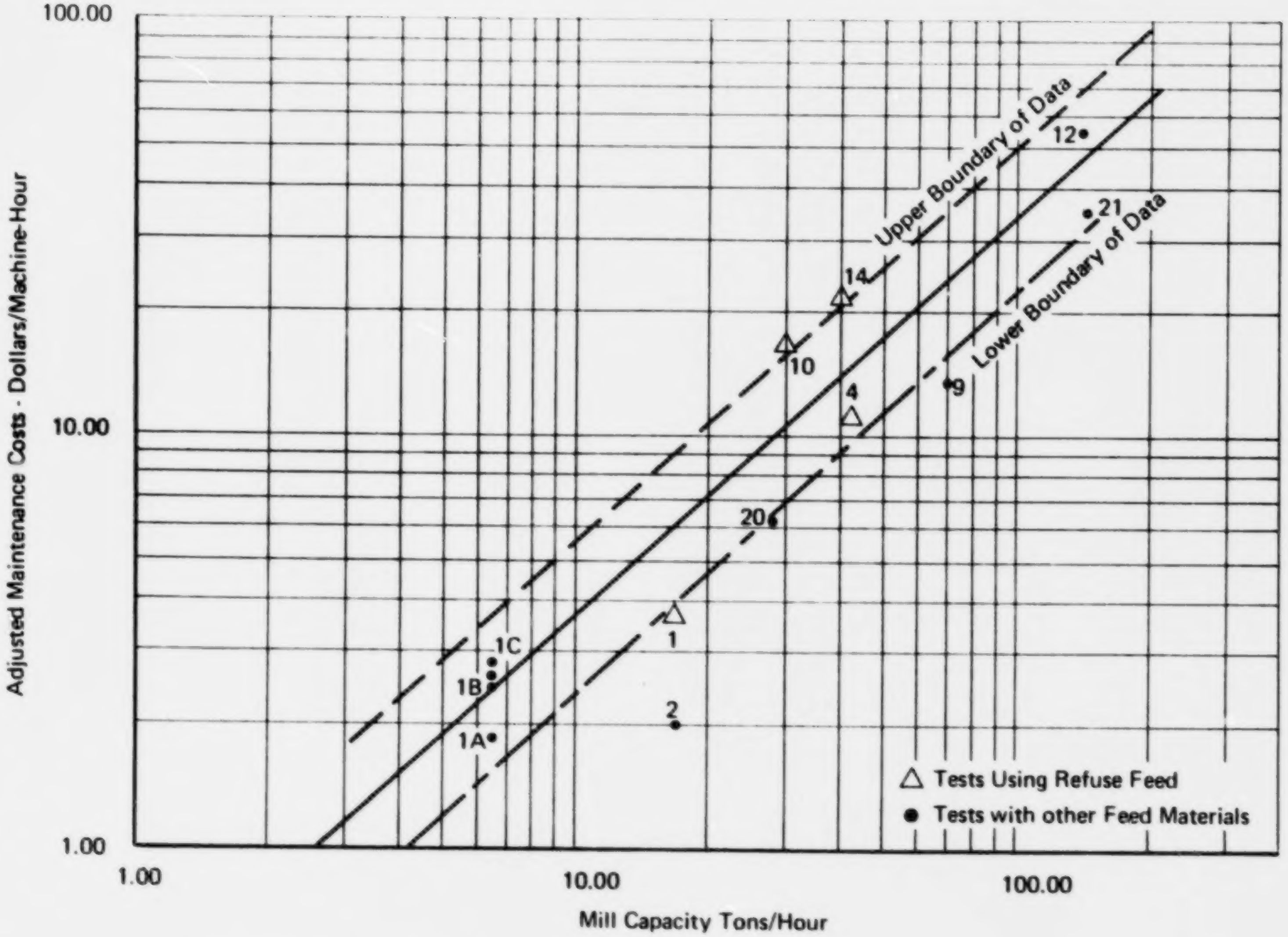


FIGURE A–2 REFUSE MILL CAPITAL INVESTMENT (6" Product Top-Size)
(Excludes Foundations, Installation, Electrical, Etc.)
(Basis - Costs FOB Boston, Mass. 1969 Dollars)



Note: Numerals on Data Points Refer to BMI Report (Ref. 1)

FIGURE A–3 MAINTENANCE COST CORRELATION–6" PRODUCT TOP SIZE

Labor was charged at the rate of $5/hr (plus 40% overhead) for one-shift operation for 250 days per year. Maintenance, modified by the product top-size factor, was calculated on the basis of the median line for the data shown in Figure A-3. Power was calculated assuming an overall electromechanical efficiency of 85% and a power cost of 1.5¢/kwh. On the basis of the Battelle data, an average value of 30 hp-hr/ton shredded (6" product top-size) was used. Note that the product top-size factor is also required here.

The total capital and operating costs for size reduction are shown in Figure A-4 as a function of incinerator plant capacity and product top-size. A sample calculation is shown in Table A-1. The relative importance of maintenance, power, fixed charges, and labor are shown in Table A-2 to permit modification to local conditions as described in the Introduction to Chapter VII.

It must be recognized that at the time of this writing, very little specific data exists on *refuse* size reduction. The conclusions given in this analysis are thus tentative. The costs shown are based on estimates which have been adjusted using empirical conversion factors. Little working experience supports our assumptions regarding labor and maintenance costs for refuse applications. As a consequence of this uncertainty, caution should be exercised in use of the results for definitive planning or budgeting. Hopefully, research now being supported by the Bureau of Solid Waste Management and other privately-sponsored work will provide information on the technical and economic feasibility of various types of size reduction equipment in the near future.

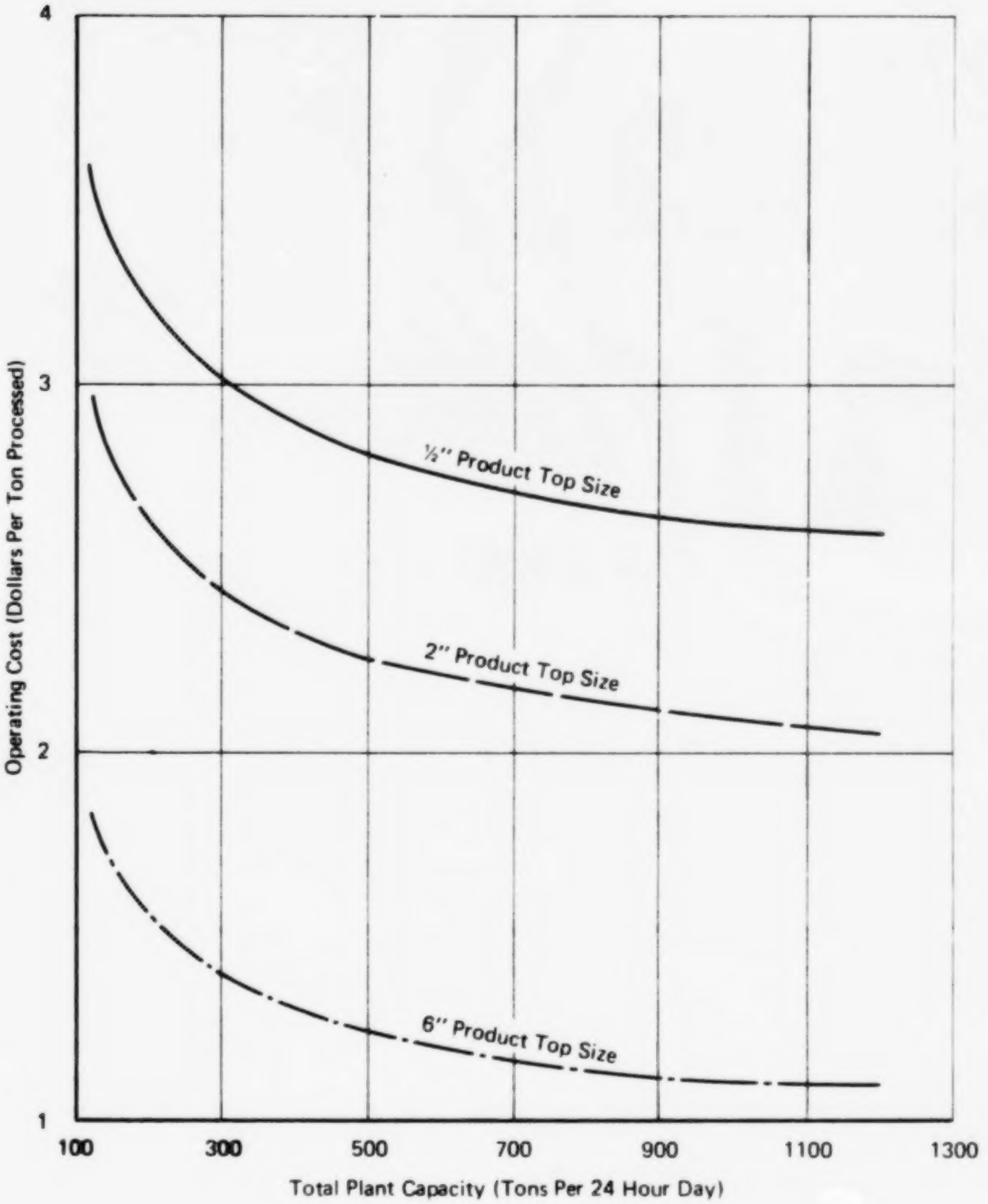


FIGURE A–4 SIZE REDUCTION – TOTAL CAPITAL AND OPERATING COSTS

TABLE A-1

SAMPLE CALCULATION - SIZE REDUCTION COSTS

Basis: 1200 TPD Incinerator Plant; 2 mills run 1 shift/day, 250 days/year at 75% average load factor

1. Mill Size = 1200/12 = 100 tons/hr for 6" top-size
   × 2.00 capacity factor = 200 tons/hr for 2" top-size
   × 2.57 capacity factor = 257 tons/hr for 1/2" top-size

2. Capital Investment (Figure A-2)

Top-Size	From Figure A-2		Total Investment
6"	$128,000/unit x 2 units x 2.4 factor	=	$ 615,000
2"	$194,000/unit x 2 units x 2.4 factor	=	931,000
1/2"	$226,000/unit x 2 units x 2.4 factor	=	1,085,000

3. Operating Costs

a. Capital Charges [15-year amortization (6.67%/yr) + 3% interest]

Top-Size	Annual Capital Charge @ 9.67%
6"	$ 59,500
2"	$ 90,000
1/2"	$105,000

b. Maintenance Charges

Top-Size	Base $/Ton x Tons/Hr x Top-Size Factor x 2000 Hrs/Yr	=	$/yr
6"	$0.345 x 200 x 1.00 x 2000	=	$138,000
2"	$0.345 x 200 x 2.00 x 2000	=	$276,000
1/2"	$0.345 x 200 x 2.57 x 2000	=	$354,660

c. Labor @ 1 man-hr/machine-hr @ $7/hr net = $14,000/yr.

d. Power @ 85% efficiency, 1.5¢ /kwh, 30 hp-hr/ton (6" top-size)

Top-Size	Factor	x	$/yr (6" top-size)	=	$/yr
6"	1.00		117,720*	=	$117,720
2"	2.00		117,720	=	$235,440
1/2"	2.57		117,720	=	$302,540

e. Total Cost

Top-Size	$/Yr	Tons/Yr	=	$/Ton
6"	$776,200	300,000		$2.59
2"	$615,440	300,000	=	$2.05
1/2"	$329,220	300,000	=	$1.10

*Assumes 2 mills, 75% average load factor, 30 hp-hr/ton @ 6" top-size.

TABLE A-2

DISTRIBUTION OF SIZE REDUCTION COSTS AMONG COST ELEMENTS

Cost Element		Plant Capacity (TPD) 120	300	600	1200
6" product	Labor	25.5%	13.5%	7.7%	4.3%
	Maintenance	26.9	34.2	38.6	41.9
	Power	21.4	28.3	32.5	35.8
	Fixed Charges	26.2	24.0	21.2	18.0
2" product	Labor	15.7%	7.7%	4.2%	2.3%
	Maintenance	33.2	39.0	42.2	44.9
	Power	26.4	32.2	35.6	38.2
	Fixed Charges	24.7	21.1	17.9	14.6
1/2" product	Labor	12.9%	6.2%	3.4%	1.8%
	Maintenance	35.1	40.5	43.5	45.6
	Power	28.0	33.5	36.5	38.9
	Fixed Charges	24.0	19.8	16.6	13.6

APPENDIX B

FLUE GAS CONDITIONING

APPENDIX B

FLUE GAS CONDITIONING

Flue gas conditioning is defined as the cooling of the flue gas after it has left the combustion zone to permit discharge to mechanical equipment such as dry air-pollution control (APC) devices and fans or a stack. In general, cooling to 450°F–700°F is necessary if the gas is discharged to mechanical equipment, while cooling to 900°F–1100°F is adequate for discharge to a refractory-lined stack.

Both wet and dry methods are used for cooling (or tempering) incinerator flue gas streams. The paragraphs below discuss the technical and economic features of several embodiments of these methods.

A. PROCESS DESCRIPTION

1. Cooling by Water Evaporation

In wet methods, water is introduced into the hot gas stream and evaporation occurs. The degree of cooling is controlled by (1) the amount and droplet size of the water which is added to the gas and (2) the residence time of the gas in the water atmosphere. Presently, two types of wet cooling are used – wet bottom method and dry bottom method.

a. Wet Bottom Methods

The wet bottom, which is most commonly used, involves the flow of large quantities of water (much more than is required for cooling the flue gas). The water is supplied by coarse sprays operated at relatively low pressures. The excess water falls to the bottom of the cooling zone and is rejected or recycled. Although not efficient, some removal of particulate occurs by droplet impingement and gravity settling in the spray chamber.

The equipment used in this system consists of several banks of sprays, each with several nozzles with relatively large openings (over 1/4"). These spray banks are normally located in the flue leading to the stack or air pollution control equipment. Pumps are not normally required, since line pressure is adequate for satisfactory operation. However, if the water is recycled, pumps are required. The bottom of the flue must be maintained water-tight to prevent leakage.

The system is generally controlled by measuring the gas temperature downstream of the sprays and modulating water flow, either manually or automatically. Generally, spare spray banks are provided which can be pressed into service quickly in response to sudden temperature increases or plugging of the spray nozzles.

The advantages of this system are that it is relatively simple, and reliable and is inexpensive to design and install. The gas is humidified during cooling, which may be somewhat advantageous for some types of air pollution control equipment (electrostatic precipitators) and disadvantageous for others (fabric filters). Also, there is a reduction in total gas volume during cooling, as shown in Figure B-1. This figure shows the change in volume of flue gas as a function of inlet gas temperature when the gas is being cooled to 500°F by means of air dilution, water evaporation, and a convection boiler.

A disadvantage of the wet bottom system is that much more water (greater than 100% excess) is used than is necessary for cooling the gas. The excess water is acidified in use and is contaminated with particulate and dissolved solids. Therefore, it normally requires treatment before it can be discharged from the plant. In some installations the excess water is recycled to the process, and in these cases severe problems of erosion, corrosion, and plugging are encountered in the nozzles, piping, and recirculation pumps. As a result, maintenance costs are excessive and equipment downtime is common. The removal of suspended solids using clarifiers, hydrocones, and settling ponds is helpful, but problems with corrosion, plugging, and erosion have not been eliminated. In some plants, the clarifiers and ponds are sources of odor. Also, ponds require considerable land area and may result in ground water pollution. Corrosion problems result from the very low pH (less than 2.0) which occurs when recirculation systems are used, and the build-up of soluble salts in the recirculated water. These problems can be controlled to some extent by adding chemicals such as lime or soda ash to the contaminated water. However, such systems have significant operating costs and do not completely alleviate corrosion problems.

Another disadvantage of the wet bottom method is that flue gas leaving the spray chamber may carry entrained water droplets or wet particulate matter. These moist particles can cause operating problems with the APC and fan equipment due to fly ash adherence and accumulation. Also, corrosion in unprotected metal parts downstream or build-up of hardened deposits of solids in the flues and fan housing can occur.

b. Dry Bottom Methods

In the dry bottom method, only enough water is added to cool the gas to the desired temperature, and the system is designed and operated to assure complete evaporation. In this system, a conditioning tower 30-90 feet high is required and fine, high-pressure spray nozzles are used. Booster pumps are necessary to raise the water pressure to assure fine atomization; water pressures from 100 to 600 psig are common in such systems. Control is usually accomplished with a temperature controller measuring the outlet flue gas temperatures and modulating the flow of water to the conditioning tower sprays. Since high pressures are required,

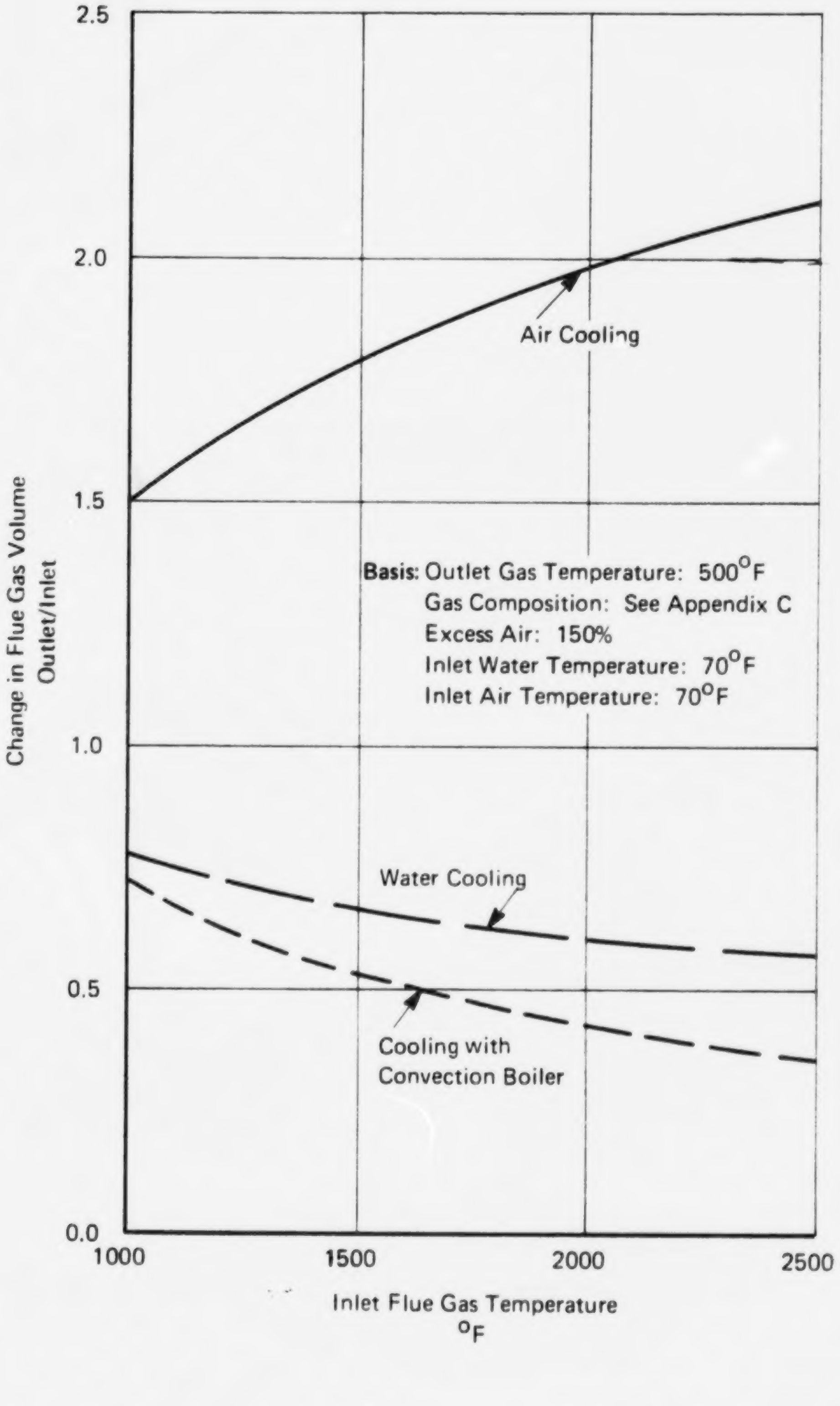


FIGURE B–1 CHANGE IN FLUE GAS VOLUME DURING COOLING TO 500°F (TO 600°F FOR BOILER) only a small degree of flow rate modulation by pressure variation is generally practical. If the flow is too low, the pressure drop across the nozzles will fall and poor atomization will result; if the flow is too great, the pressure drop across the nozzle will increase and limit flow. As a result, additional spray heads are put into or taken out of service as required to maintain uniform outlet temperatures.

Water droplet size is very important in the design of a dry bottom conditioning tower; droplets that are too large will not completely evaporate and, in addition to the problems of water carry-over described above, will cause a wet bottom in the conditioning tower. Droplets which are too fine will lead to high power usage. A balance must be made among droplet size, gas residence time in the tower, and power usage. Equation (1) presents a formula developed by Mr. L. Hardison, of U.O.P. Air Correction Division, for estimating the evaporation time of water droplets:[1]*

$$t = \frac{R}{0.222\,(Tg - Td)} \qquad (1)$$

where

t = residence time in seconds
R = droplet radius in microns
Tg = temperature of gas (°F)
Td = temperature of droplet (°F)

A second and more complex method of estimating (in a step-wise fashion) the evaporation time of droplets (up to about 600μ) uses the graph shown in Figure B-2 where:

Ta = gas temperature (°K)
Δt = Ta-54 (°C)
μ_a = gas viscosity at Ta (gm/cm sec)
β = $0.071\,(\mu_a^2\,T_a)^{-0.36}$

If the drop temperature varies significantly from 130°F (54°C), the evaporation time may be corrected by a factor $(Ta-54)/(Ta-T_{drop})$; where T_{drop} is in °C. It is suggested that users of this latter method consult the original paper.[2]

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*All superscript numbers refer to the list of references (Section D) at the end of this appendix.

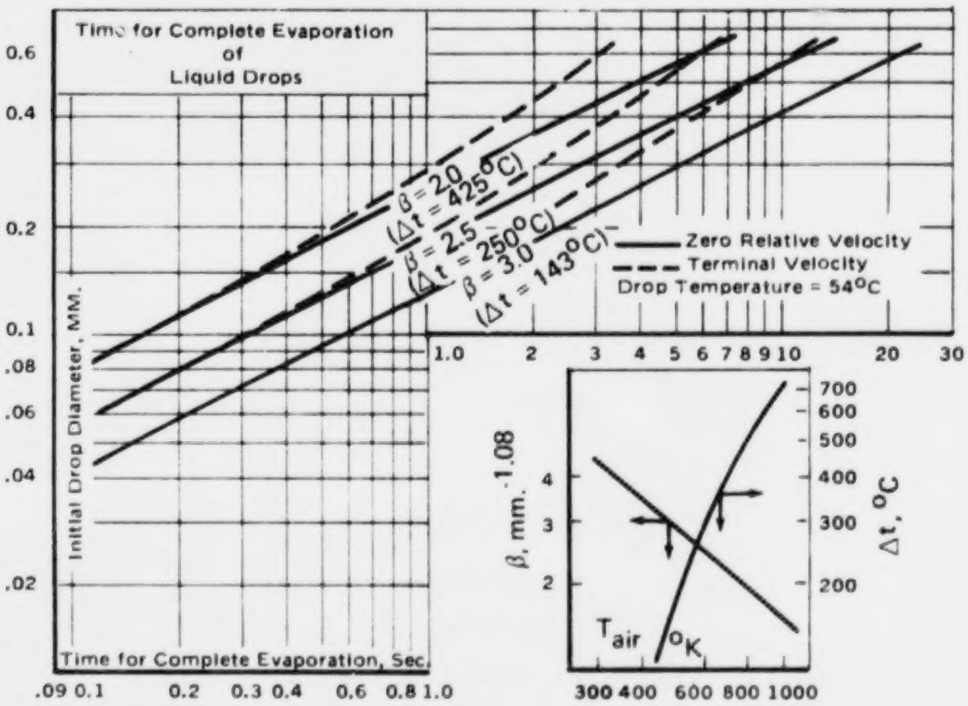

FIGURE B–2 THEORETICAL EVAPORATION TIMES FOR WATER DROPLETS IN HOT GAS STREAMS

Although both of these methods are useful in estimating the residence time required for evaporation, care must be taken in selecting a nozzle which provides uniform-size droplets rather than droplets with a wide size distribution, since the largest droplet will dictate the length of the conditioning tower.

Table B-1 shows the effects of spray tower evaporation on flue gas properties. These data can be used for both wet and dry bottom systems; however, for wet bottom systems, the evaporation rate shown assumes all water fed to the conditioning tower is evaporated. In actuality, additional water will be used, since in wet bottom systems it is not uncommon to add either 100-200% excess water.

The advantages, of the dry bottom system are that it minimizes water consumption, eliminates water pollution problems, produces a "dry" effluent gas (free from entrained water), and reduces the volume of the flue gas as shown in Figure B-1. The gas is humidified during cooling, which may or may not be desirable. The disadvantages of the system are that it is expensive to design and install, power consumption is high, control is somewhat complex, and the small orifices of the atomizing nozzles make them susceptible to plugging. The nozzle plugging can be minimized by filtration of the water, proper draining of the nozzles when they are not in use, and maintenance of sufficient flow through the nozzles to keep them cool. A recent installation in New York used a spray head in which a portion of the water flow was recycled, thus providing additional nozzle

TABLE B-1

EFFECT OF SPRAY TOWER WATER EVAPORATION ON FLUE GAS PROPERTIES[a]

Combustion Air		Evaporation Rate - Pounds of Water Per Pound of Refuse					
		0	0.5	1.0	1.5	2.0	2.5
0% Excess Air (3.21 lb/lb refuse)	T	3050	2294	1736	1286	926	620
	C	514	481	446	404	360	311
	V	100	93	87	78	70	60
	D	145	162	172	179	183	[illegible]
25% Excess Air (4.01 lb/lb refuse)	T	2690	2060	1574	1178	854	584
	C	551	512	471	425	378	330
	V	100	93	85	77	69	60
	D	139	156	167	174	179	183
50% Excess Air (4.81 lb/lb refuse)	T	2402	1862	1430	1088	800	548
	C	581	537	490	445	398	347
	V	100	92	84	77	68	60
	D	133	151	162	169	175	179
75% Excess Air (5.62 lb/lb refuse)	T	2168	1700	1322	1016	746	512
	C	608	561	513	467	415	362
	V	100	92	84	77	68	59
	D	128	147	158	165	171	175
100% Excess Air (6.42 lb/lb refuse)	T	1970	1574	1232	944	710	494
	C	631	586	535	484	436	383
	V	100	93	85	77	69	61
	D	124	143	154	162	167	172
125% Excess Air (7.22 lb/lb refuse)	T	1808	1448	1142	890	656	476
	C	653	604	552	503	448	402
	V	100	92	84	77	68	61
	D	121	140	151	159	165	169
150% Excess Air (8.02 lb/lb refuse)	T	1682	1358	1070	836	638	440
	C	678	627	571	520	471	412
	V	100	92	84	77	70	61
	D	117	136	148	155	161	166
175% Excess Air (8.83 lb/lb refuse)	T	1556	1268	1016	800	602	422
	C	695	645	592	541	486	429
	V	100	93	85	78	70	62
	D	114	133	144	154	160	164
200% Excess Air (0.63 lb/lb refuse)	T	1466	1196	962	764	566	404
	C	719	665	611	560	499	444
	V	100	92	85	78	69	62
	D	112	131	142	150	157	161
250% Excess Air (11.23 lb/lb refuse)	T	1304	1070	872	692	530	386
	C	758	701	648	593	537	483
	V	100	92	85	78	63	64
	D	107	126	138	146	152	158
300% Excess Air (12.84 lb/lb refuse)	T	1160	962	800	638	494	350
	C	788	732	684	627	572	508
	V	100	93	87	80	73	65
	D	103	122	133	142	149	154
350% Excess Air (14.44 lb/lb refuse)	T	1070	890	728	584	458	322
	C	831	771	712	655	602	542
	V	100	93	86	79	72	65
	D	99	118	130	138	144	150

[a] Explanation of Symbols

T Flue gas temperature (°F)
C Flue gas rate (CFM per TPD capacity)
V Ratio of the actual flue gas volume to the volume before water evaporation (as a percent)
D Flue gas dew point (°F)

Source: This analysis is based on the average refuse composition presented in Section IVB, Volume I of this report.

cooling. The effectiveness of this approach is not known at the time of this writing. Keeping the nozzles cool and draining them is essential to prevent scale formation in the nozzles due to water hardness: this scale is the principal cause of plugging. In order to minimize the risk of outages, the nozzles should be easily accessible and removable during operations, and additional nozzles should be provided for emergency use.

The dry bottom system is more costly than the wet bottom system because of the need for water filtration and the maintenance required for the high-pressure pumps, nozzles, and control systems. Proper materials of construction (such as Carpenter 20 stainless steels) are essential for good nozzle life and to minimize corrosion. Power consumption can be minimized by proper nozzle selection and, with increased investment costs, by installing larger conditioning towers (providing longer residence time) which permit less fine atomization.

2. Cooling by Air Dilution

Dilution with air is the simplest and most reliable method for flue gas cooling. Only a damper for air control is necessary for a system with adequate draft. Although air dilution has these advantages, large quantities of air are required for air dilution cooling, increasing the demands placed upon the APC equipment and the induced draft fan or stack. The increase in volume caused by air cooling is shown in Figure B-1. Such large increases in volume significantly increase the capital and operating costs of the equipment which follows the point at which dilution takes place. For these reasons, air dilution should not be used in new incinerator installations.

3. Cooling by Heat Withdrawal

The second method of dry conditioning uses a convection boiler in which heat is removed from the flue gas by the generation of steam. The equipment consists of a convection tube waste heat boiler, economizer, and all of the auxiliary equipment required, such as boiler feed water pumps, steam drums, and water treatment facilities. In addition, an air or water condenser (the latter served by a nearby natural cooling water source or cooling tower) may be necessary to condense the steam when the steam demand is less than the generation rate. These boilers would have controls similar to conventional boilers and would probably require an additional full-time operator – a licensed stationary engineer.

The advantages of this system are that heat is recovered and that the shrinkage in flue gas is greater than with any other method discussed, as shown in Figure B-1. No water is added to the system during cooling which may or may not be desirable. In some cases, the steam generated in the boiler can be sold and produce income, or the steam can be used in the plant to induce mixing in the incinerator furnace gases (steam jets) or for space heating.

The disadvantages of this method are that the system is expensive to design and install, the boiler installation is complex to operate and requires an experienced licensed operator, corrosion and erosion problems with the boiler tubes have not been completely resolved, sticking of fly ash on the boiler tubes can occur, and reliable markets for the steam must be found.

B. CAPITAL AND OPERATING COSTS

Capital and operating costs have been prepared for each of the systems described above as a function of the volume flow rate of the *treated* gas. This flow rate may be developed from the furnace outlet flow rate using Table B-1 and the volume reduction ratio from Figure B-1. These costs are for the flue gas conditioning system only, as it was assumed that these components were separable investment modules which would be added to an incinerator complex.

1. Capital Costs

The capital cost of each of the systems is shown in Figure B-3. The costs of the 250 and 400 psig saturated steam convection boilers (curves 1 and 2) include the boiler, economizer, piping, feedwater pumps, air-cooled condenser, deaerating heater, valves, water treatment and controls, on an installed cost basis with structural steel. It should be noted that for systems on furnaces smaller than 175 tons per 24-hr day, use of package boilers would reduce the capital investment approximately 25%. It was assumed that the boiler would be installed in the flues following the combustion chambers of an incinerator. Since boiler costs are closely related to heat transfer area, which is dictated by temperature differentials, the boiler costs are based on specific gas inlet and outlet conditions [1500°F inlet (approximately 200% excess air) and 600°F outlet].

Curve 3 shows the cost of a dry bottom evaporative cooling spray tower, complete with filters and an air compressor. For this plot, a 60-foot-high tower constructed of unlined 316 ELC stainless steel was assumed. The water system would operate at 200 psig, and the nozzles would be automatically blown dry with compressed air when taken out of service.

Curve 4 shows the cost of the high-pressure spray system, exclusive of the conditioning tower. These costs are useful in estimating the investment to convert an existing coarse spray wet bottom cooling system to dry bottom operation.

Curve 5 shows the cost of a coarse spray system using water on a once-through basis. The costs include the sprays, piping, and instrumentation required. It was assumed that city line water pressure would be adequate for atomization. If a recirculation system is used, the cost of this system would increase 2-4 times depending on the size of the settling pond, the water recirculation rate, and the chemical addition system used.

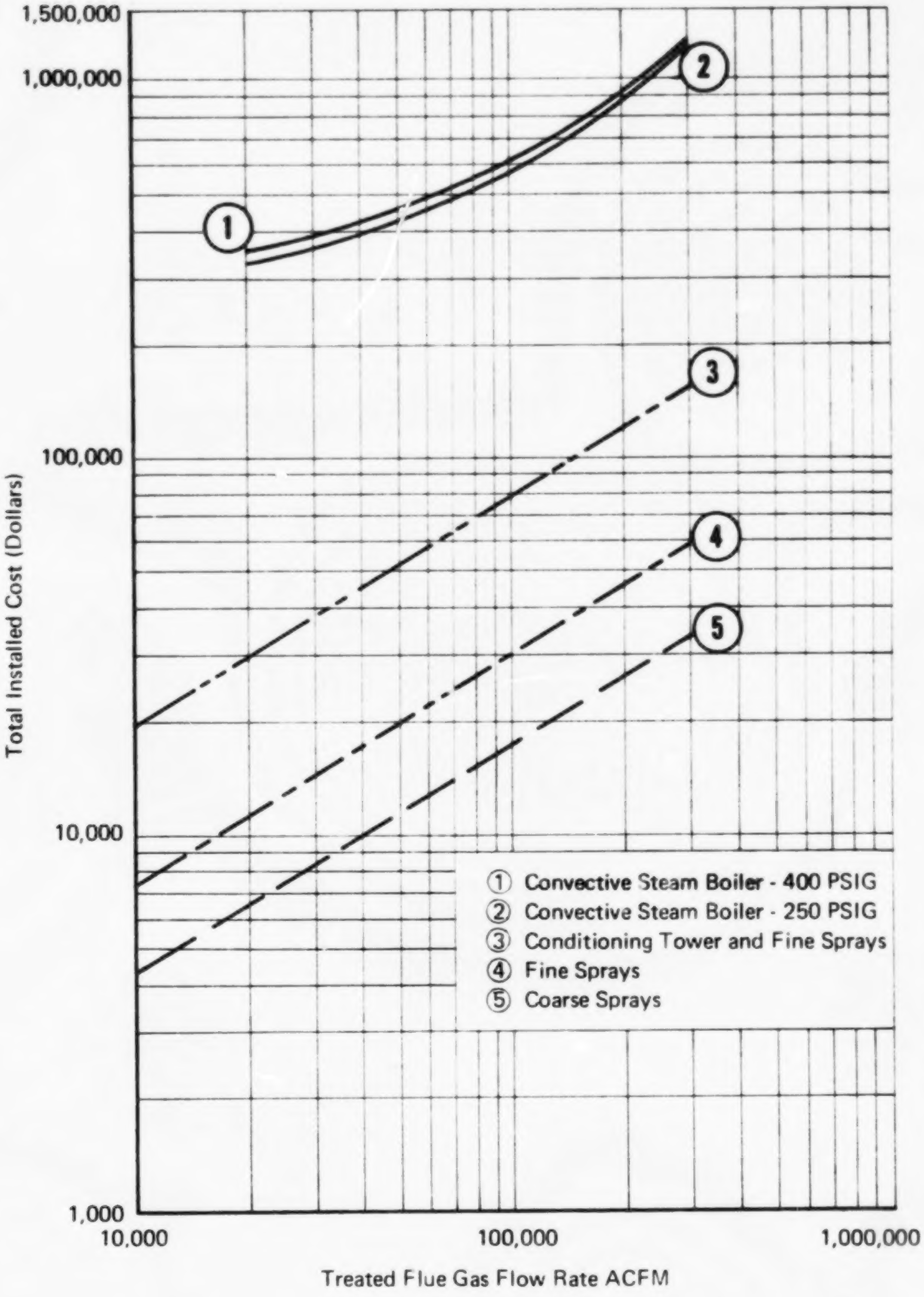

FIGURE B–3 FLUE GAS CONDITIONING SYSTEMS TOTAL INSTALLED EQUIPMENT COST

No costs have been estimated for air dilution cooling since only a controlled air opening would be required. The true total cost of using this system is reflected in the increased size of other equipment (APC systems, fans, flues, stack) following the point of air dilution.

2. Operating Costs (including annual amortization and interest)

Operating costs for the convection boiler, evaporative cooling tower with fine sprays, and coarse spray cooler for 1-, 2-, and 3-shift operation are shown in Figures B-4, -5, and -6. Except for the boiler systems, these costs were based on cooling the flue gas from 1650°F to 500°F. The gas composition was based on the refuse analysis shown in Appendix C, and it was assumed that 150% excess air was used.

The operating costs for the convection boiler were based on a 250-psig boiler system requiring one operator per shift. Boiler feed water chemical costs were estimated at 0.4¢/1000 lb steam, and power was estimated at 1.5¢/kwh. Maintenance was estimated at 2%, 3%, and 4% of investment cost for 1, 2, and 3 shifts, respectively. Amortization was assumed to be over 15 years, and annual interest was assumed at 3.14% of the total investment. No steam credits were taken (see Appendix F). Table B-2 shows the distribution of costs as described in the Introduction to Section VII.

TABLE B-2

DISTRIBUTION OF TOTAL OPERATING COSTS FOR CONVECTION BOILERS

CFM Treated	20,000			100,000			200,000		
Shifts/Day	1	2	3	1	2	3	1	2	3
	%	%	%	%	%	%	%	%	%
Category									
Labor	26	40	48.2	17.4	27.9	34	12	20	25
Power	0.4	0.4	0.5	0.7	1.2	2	1.1	2	2
Water Treatment	0.2	0.3	0.3	0.6	0.9	1	0.9	1	2
Capital	60.4	45.3	36	67.3	54	45	71	59	50
Maintenance	13	14	15	14	16	18	15	18	21
Total	100	100	100	100	100	100	100	100	100

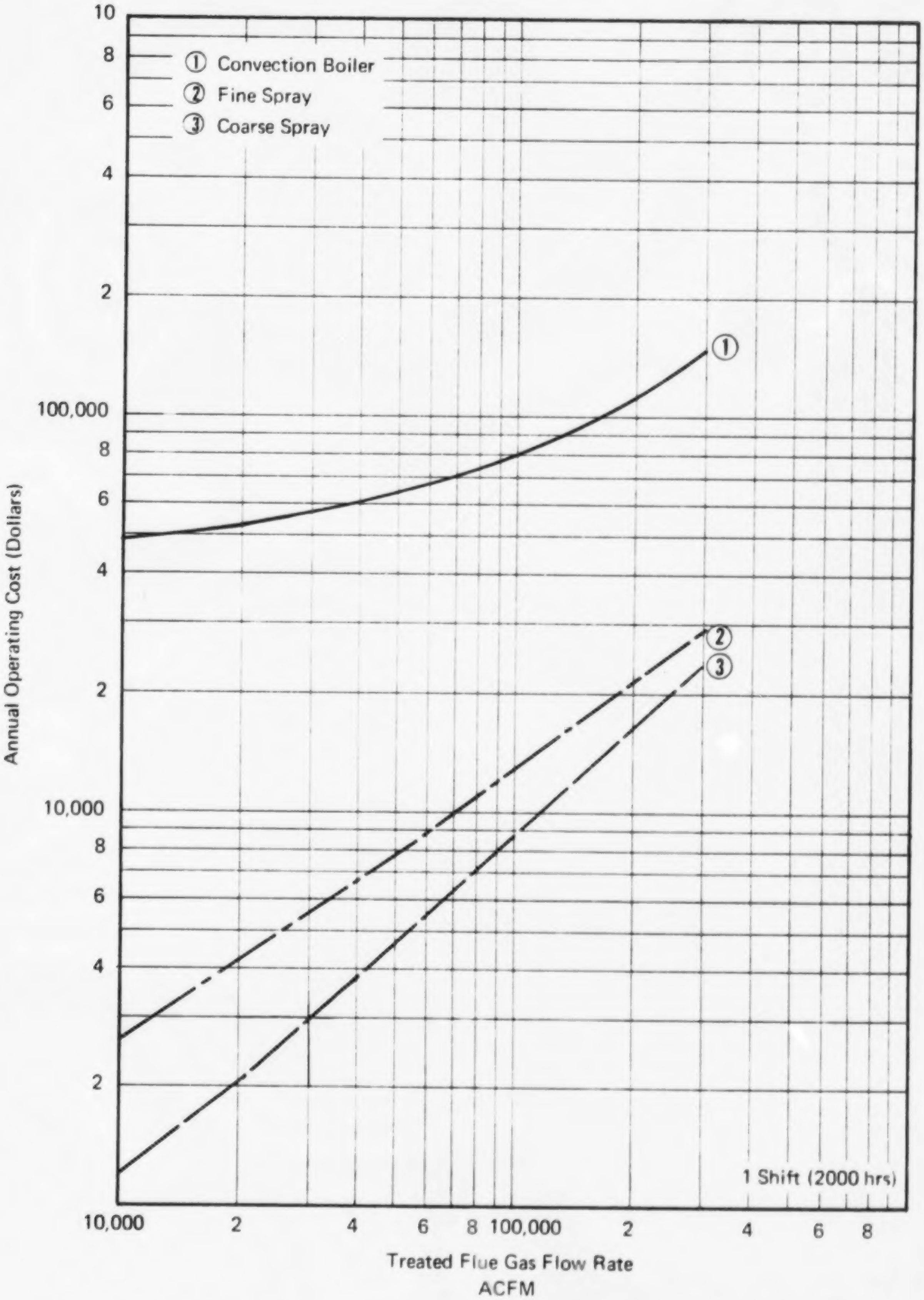

FIGURE B–4 FLUE GAS CONDITIONING–ANNUAL OPERATING COST

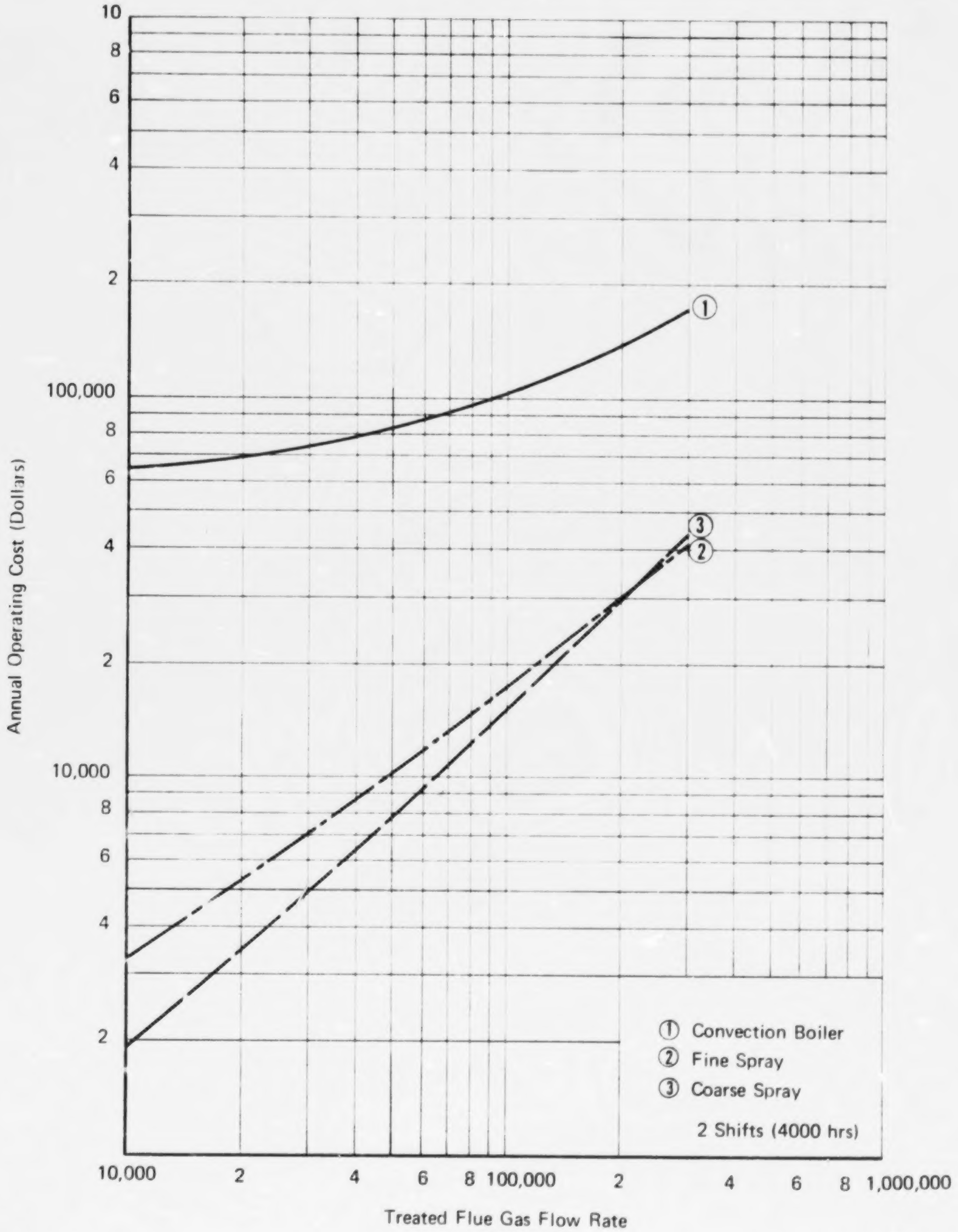

FIGURE B–5 FLUE GAS CONDITIONING: ANNUAL OPERATING COST

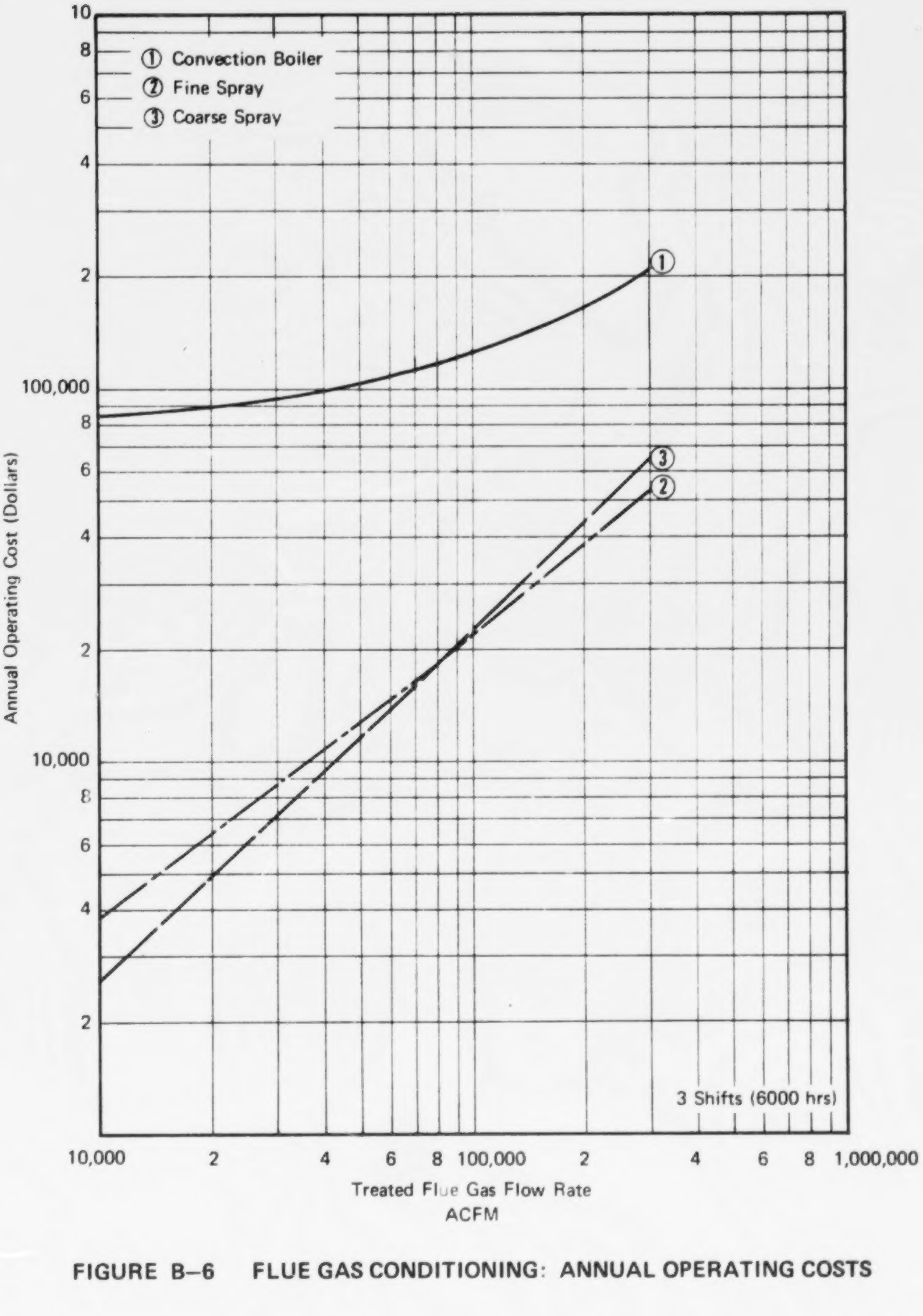

FIGURE B–6 FLUE GAS CONDITIONING: ANNUAL OPERATING COSTS

The coarse spray cooling system costs assume that 100% excess water (over that actually required for cooling) is used and that the excess water is rejected to the sewer at no additional cost. Water is estimated to cost 30¢/1000 gallons; and maintenance, amortization, and interest costs are estimated to be the same percent of investment as for the convection boiler system. Figure B-7 shows the cooling water requirements in gallons per 1000 cu ft of *treated* flue gas to cool flue gases from a range of inlet temperatures to 500°F. This figure would provide a means to adjust annual operating costs if the inlet temperature differed from 1650°F, the basis used for the cost estimates.

The costs for the evaporative tower cooling system are based on a system operating at 200 psig. Power and water unit costs are assumed to be the same as for the other systems as is maintenance, depreciation, and interest. Figures B-7 and B-8 provide a basis for adjusting costs for various inlet temperatures and water atomization pressures. It is assumed that water at 50 psig is available at the pump inlet.

It is of interest to note that, in the larger-size plants, the evaporative system is less expensive to operate than the coarse spray system for multishift operation. The savings in water consumption in these larger plants offset increased capital costs and power costs.

No operating cost estimates have been prepared for the air dilution system, since essentially no costs are encountered at the point of dilution. However, greater total operating costs in other parts of the system will result if air dilution cooling is used. Figure B-9 shows the volume of air required to cool flue gas to 500°F at various inlet gas temperatures. The cooling air is assumed to be at 70°F.

C. STEAM PLUMES

In the incineration process, water is introduced into the flue gas from the evaporation of refuse moisture and as a result of the combustion process. Water may also be added during conditioning of the gases and by wet scrubbing. As a result, the flue gas leaving the stack can contain significant amounts of water vapor which will condense, under certain atmospheric conditions, and an opaque stack effluent (steam plume) will result. Although steam plumes neither cause nor indicate air pollution (often quite the contrary), public reaction is frequently negative and vocal. While these plumes will appear white and not unpleasing in bright sunlight, on cloudy days and at twilight, they may seem dark and "dirty."

Formation of a steam plume depends upon the discharge temperature and moisture content of the flue gases, the ambient temperature and the amount of dilution which occurs at the point of flue gas discharge. The processes which occur upon discharge of the stack gases into the ambient are as follows:

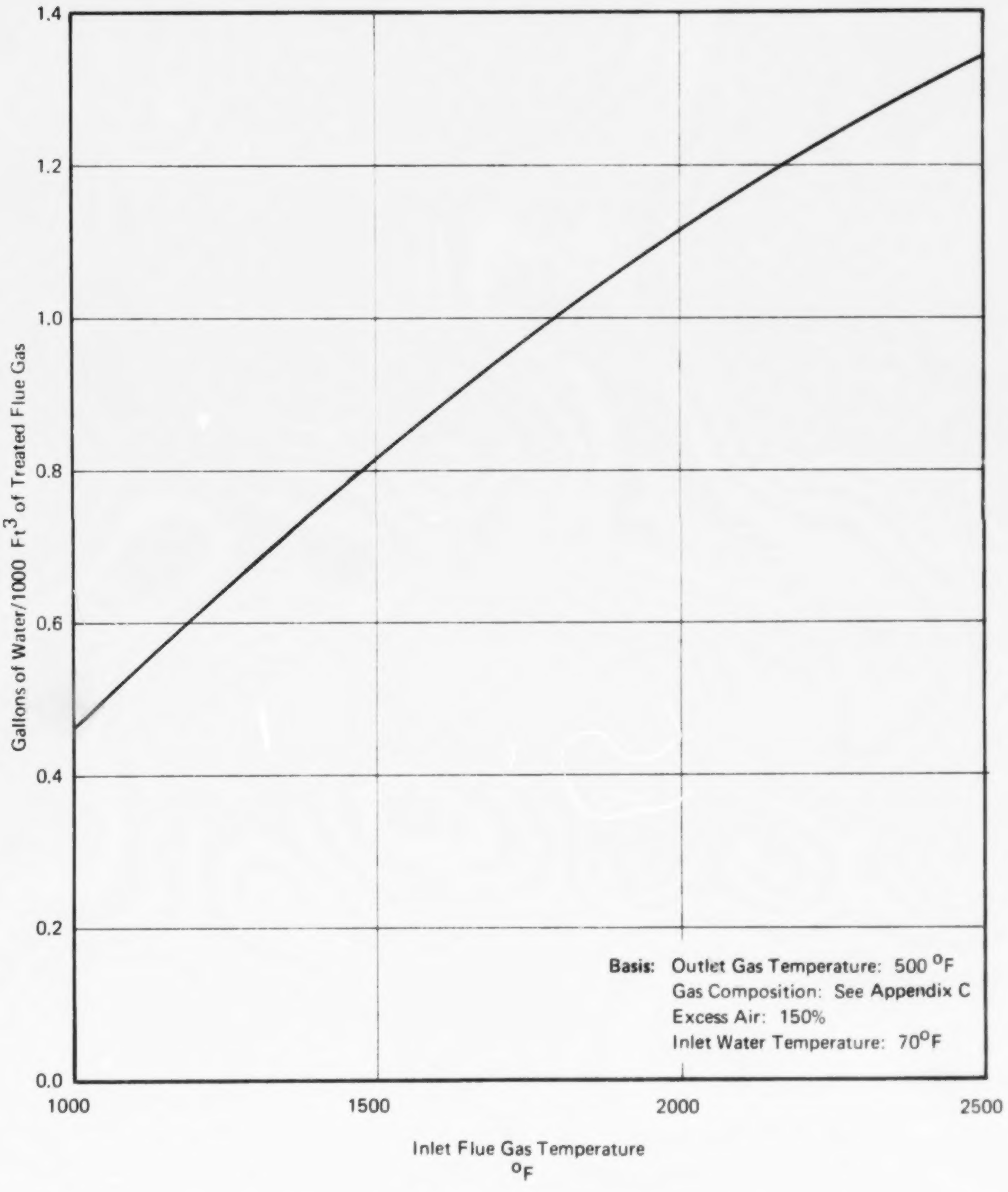

FIGURE B–7 WATER CONSUMPTION FOR FLUE GAS COOLING

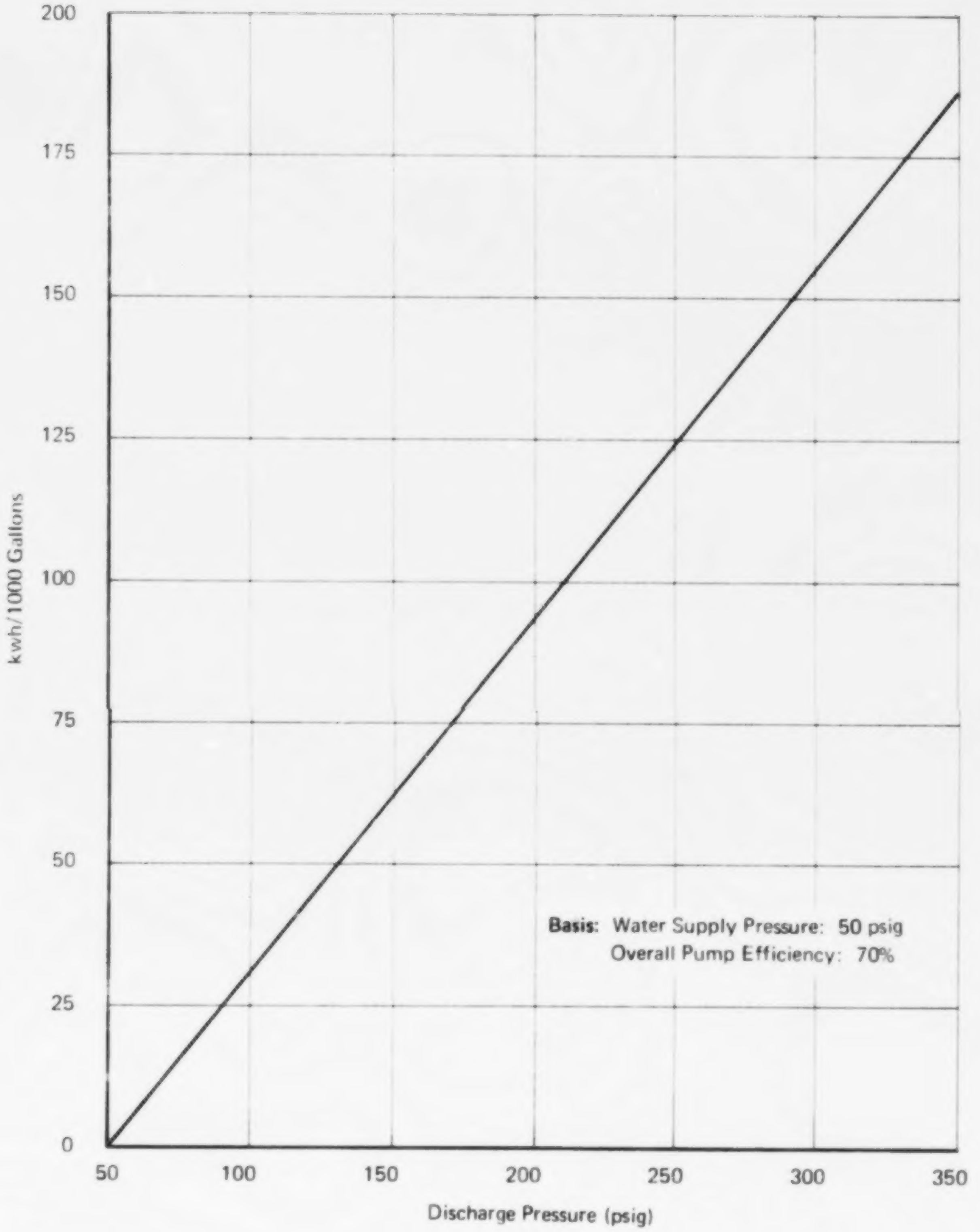

FIGURE B–8 POWER REQUIREMENTS FOR FINE SPRAY COOLING SYSTEMS

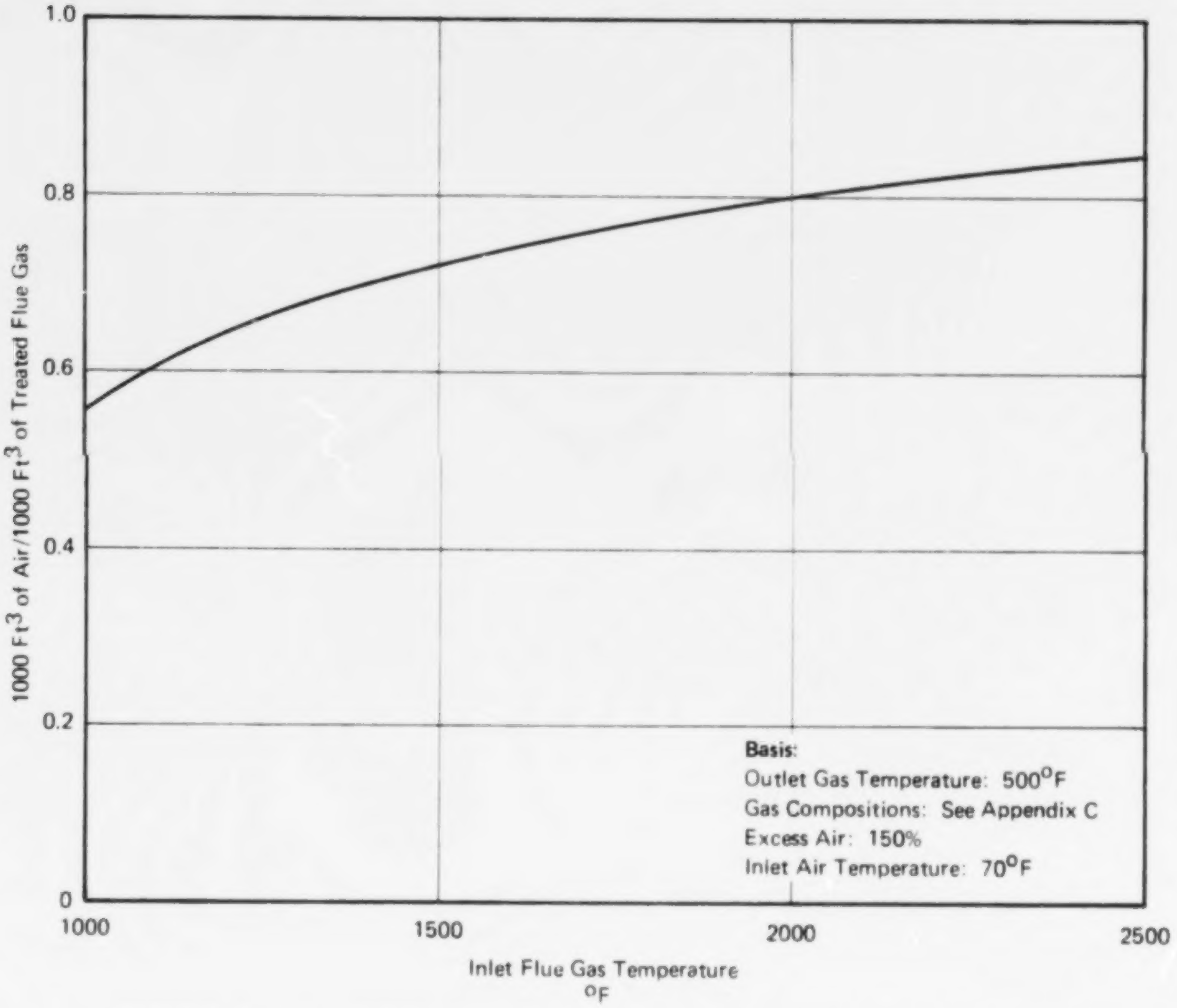

FIGURE B–9 AIR REQUIREMENTS FOR DILUTION COOLING OF FLUE GAS

(1) The gases rise from the stack following the flow pattern of a free turbulent nonisothermal jet (sometimes in cross-flow due to winds).[3] One characteristic of this flow pattern is that little mixing of the jet fluid with the ambient occurs for a distance of about one stack diameter. As a result, the plume from superheated vapors may "float" above the top of the stack.

(2) The stack gases then begin to mix with the cooler ambient air. As this occurs, the temperature and absolute humidity of the mixed gas falls, about in proportion to the dilution ratio (pounds of stack gas per pound of ambient fluid). Thus, the state of the gas mixture, as shown on a temperature-humidity (psychrometric) chart, moves downward and to the left (see Figure B-10). The curve describing the gas state differs from a straight line (between the stack discharge and ambient temperature and humidity point) only as a result of differences in relative specific heat between the flue gas and the ambient air. This effect is often neglected, however, as it acts, in the analysis which follows, to yield a conservative estimate.

(3) The mixed gas state thus moves from stack conditions toward cooler and less moist conditions. If, in the course of this change, the mixed gas conditions cross the saturation curve (Figure B-10), a steam plume will form. The gaseous part of the plume then "moves" down the saturation curve while liquid water, in the form of small droplets, is released. The degree of the resultant plume opacity is related to the amount of water to be condensed, the dilution process (which affects cooling rate and droplet number and size distribution), and the ambient temperature and humidity.

(4) As dilution proceeds, the condition of the gaseous part of the plume drops from the saturation curve, and the liquid droplets evaporate. At this point, the plume has "dissipated," and any residual opacity is due to suspended particulate or aerosols. Typically, however, the high dilution at this distance from the stack effectively hides what may have been an intolerable plume opacity caused by high fly-ash loading.

In the case where the flue gas is evaporatively cooled from 1650°F to 500°F, the treated gas will contain approximately 0.36 lb of water vapor per lb of dry air. This moisture includes water formed by refuse combustion in addition to that evaporated in cooling the flue gases. Under these conditions, a line drawn on a psychrometric chart (see Figure B-10) starting at 500°F, 0.36 humidity, and tangent to the saturation line, delineates the set of atmospheric conditions under which a steam plume will form. The shaded area on Figure B-10 shows these

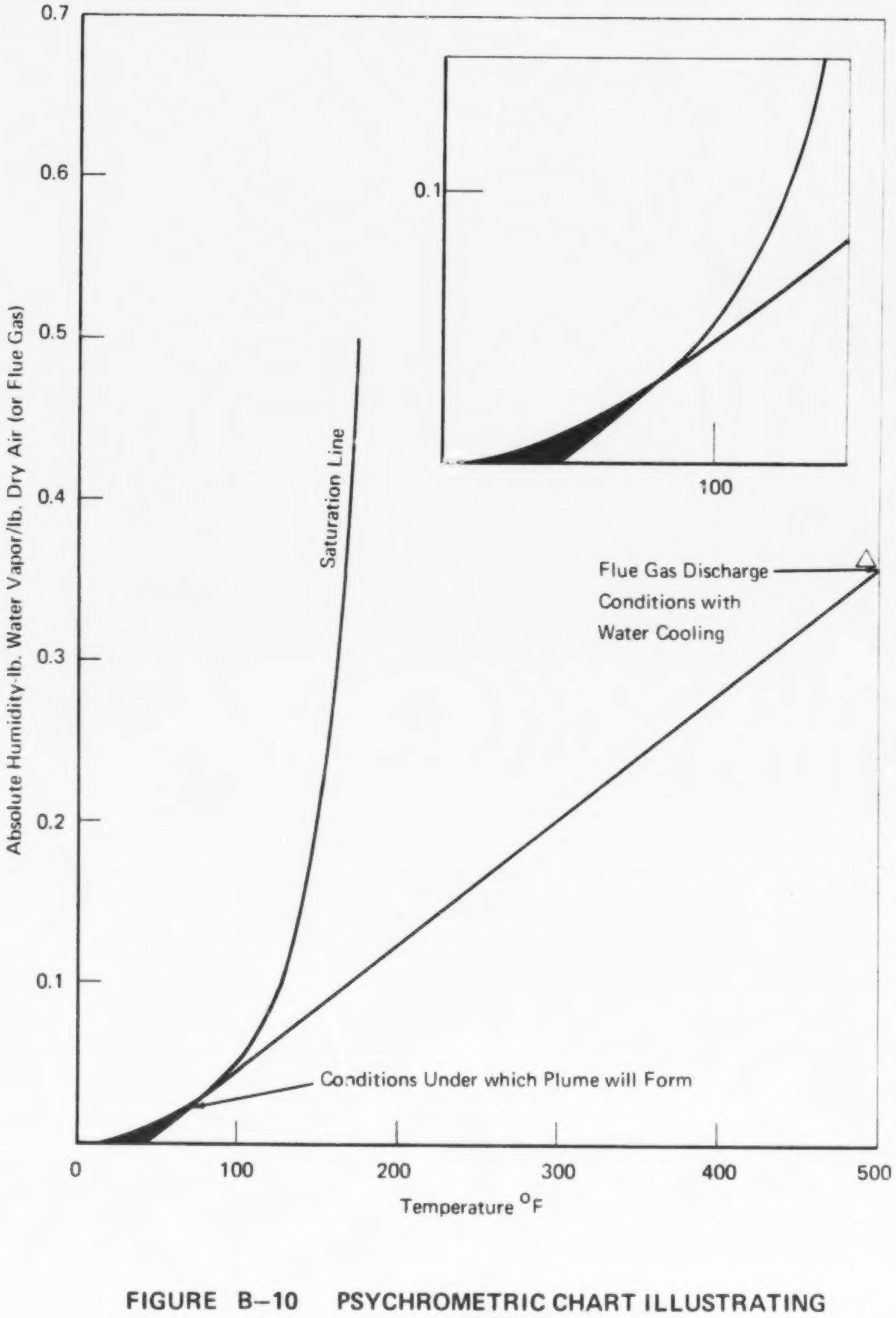

FIGURE B–10 PSYCHROMETRIC CHART ILLUSTRATING STEAM PLUME FORMATION conditions. For this flue gas, a plume will form at any time the ambient temperature falls below 40°F. The plume will also form at higher ambient temperatures, depending upon the absolute humidity of the ambient (falling within the shaded area).

If the flue gas is cooled to lower temperatures, say to 190° – 220°F in a wet scrubber, or if the ambient relative humidity is high, plumes will form at higher ambient temperatures. High cross-winds, providing more rapid dilution, may shorten or almost eliminate the plume. Reheat of flue gas, though very costly, will reduce the intensity or frequency of plume formation.

Since the costs of reheat will be excessive in regions of frequent low ambient temperature, it is likely that steam plumes (though possibly seasonal) will always be associated with incinerators equipped with wet scrubbers and with plants using evaporative cooling for flue gas conditioning. A number of authors have suggested that steam plumes may be reduced by subcooling the flue gases with a secondary scrubber to condense a portion of the water vapor before discharge, although this still requires a modicum of reheat. In fact, however, the heat removal required to condense this water must be compensated for in a cooling tower system (or equivalent). Such treatment, therefore, only moves the steam plume from the stack to the adjacent cooling tower. References 4 and 5 further discuss the steam plume problem.

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APPENDIX C

REFUSE STOICHIOMETRY

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REFUSE STOICHIOMETRY

The incinerator, like many other processing systems, receives matter and energy in one form (refuse) and discharges it, appropriately transformed (burned), in one or more other forms (flue gas, ash, sensible and latent heat, etc.). A knowledge of the relative flows of the principal material and energy streams is helpful to an understanding of this process. This appendix develops these quantities for refuse burning systems.

It must be recognized that this analysis is valid only for the refuse composition and combustion assumptions used. For different refuse compositions, the results presented here will be somewhat in error. At the time of this writing, however, this composition and the derived quantities correspond to our best estimate of average U.S. refuse. The calculation method and the breakdown of the composition of the refuse categories, however, can be used, if appropriate, to develop similar data for other refuse compositions.

Table C-1 is based upon the standard refuse composition derived by review of refuse composition data presented in Chapter IV of this report. For this stoichiometric analysis, it is assumed that all organic material is completely burned. Sulfur compounds appearing in refuse are assumed to burn to sulfur dioxide. Metals are assumed to be unoxidized. The validity of these assumptions is dependent upon the incinerator type and operating practices; poor burnout, in particular, will reduce the amount of carbon dioxide formed per ton processed. Since over 91% of the stoichiometric oxygen for combustion is used by carbon, however, the carbon dioxide and oxygen flue gas analyses (by Orsat) remain good indicators of excess air levels. The actual fraction of the metal in refuse which is oxidized is highly uncertain. In most incinerators, however, substantial amounts of unoxidized metal can be seen on the discharge grate, and the assumption that the metal is unoxidized would therefore not seem to be a significant source of error.

Part I of Table C-1 presents the ultimate analysis of refuse categories by oxidizable elements and inerts on the basis of data presented in Table IV-11. Part II of Table C-1 summarizes the total refuse "ultimate" analysis for various elements or compounds in refuse. "Bound hydrogen" and "bound oxygen" refer to the proportions of those elements which are exactly balanced to form water. Thus, "bound hydrogen" has no oxygen requirement from the combustion air supply (it being supplied from refuse oxygen), whereas hydrogen in excess of this requires oxygen from the combustion air stream. Part III of the table indicates the net stoichiometric (theoretical) air requirement. Part IV of Table C-1 indicates the flue gas composition on the basis of 100 lb of refuse. The flue gas composition which is given on a dry basis is that which would be measured in an Orsat apparatus.

Figure C-1 shows the calculated relationship between the oxygen and carbon dioxide concentrations in the flue gas stream at the furnace exit (dry basis) as it would be measured with an Orsat apparatus. The flue gas temperature is also shown based on a higher heating value (water condensed) of 4450 Btu lb refuse. These temperatures would be invalid in the case where water evaporation has occurred in water-sprayed settling chambers or other wet flue gas conditioning systems temperatures or where a boiler system withdraws heat from the flue gases. Temperatures corresponding to these modified conditions are presented in Appendix B.

A

TABLE C–1

REFUSE STOICHIOMETRY

Category	Wt %[a] "As Fired"	Wt %[a] "As Discarded"	% Moisture[a] "As Discarded"	Composition of Average Refuse in Lb/100 Lb Dry Solids[a] Lb Ash	Lb C	Lb H_2	Lb O_2	Lb S	Lb N_2	Wt (lb)
Metal	8.7	8.2	2.0	10.13	0.50	0.067	0.481	0.0011	0.0056	11.19
Paper	44.2	35.6	8.0	2.74	20.70	2.781	19.193	0.0547	0.1368	45.59
Plastics	1.2	1.1	2.0	0.17	0.90	0.125	0.285	0.0045	0.0150	1.50
Leather and Rubber	1.7	1.5	2.0	0.24	1.23	0.170	0.390	0.0062	0.0205	2.05
Textiles	2.3	1.9	10.0	0.08	1.10	0.152	0.995	0.0048	0.0523	2.38
Wood	2.5	2.5	15.0	0.09	1.43	0.178	1.260	0.0033	0.0089	2.96
Food Waste	16.6	23.7	70.0	2.17	4.13	0.574	2.730	0.0248	0.2772	9.90
Yard Waste	12.6	15.5	50.0	0.54	5.31	0.701	3.890	0.0378	0.3129	10.79
Glass	8.5	8.3	2.0	11.21	0.06	0.008	0.041	–	0.0034	11.32
Miscellaneous	1.7	1.7	2.0	1.62	0.30	0.046	0.278	–	0.0696	2.32
	100.0	100.0		28.99	35.66	4.802	29.543	0.1372	0.9022	100.00

a. These bases are shown in Chapter IV.

II. Average Refuse Summary (as fired basis: 100 lb average refuse)

Component	Wt %	Moles	Required Moles O_2
Moisture (H_2O)	28.16	1.564	0
Carbon (C)	25.62	2.135	2.135
Hydrogen (H_2-bound)	2.65	1.326	0
Oxygen (O-bound)	21.21	1.326	0
Hydrogen (H_2)	0.80	0.399	0.199
Sulfur (S)	0.10	0.003	0.003
Nitrogen (N_2)	0.64	0.023	0
Ash	20.82	–	0
Total	100.00		2.337

Higher Heating Value (water condensed) 4450 Btu/lb
Lower Heating Value (water as vapor) 3900 Btu/lb
(See also Table H-2, Appendix H)

III. Stoichiometric Air Requirement (as fired basis: 100 lb average refuse)

Moles Oxygen = 2.34

Moles Nitrogen = 8.79

11.13 moles "air" = 321 lb

IV. Flue Gas Composition (as fired basis: 100 lb average refuse)

Component	Stoichiometric			50% Excess Air		
	Moles	Mole %	Mole % Dry Basis	Moles	Mole %	Mole % Dry Basis
Moisture (H_2O)	3.455	23.98	0.00	3.455	17.29	0.00
Carbon Dioxide (CO_2)	2.135	14.82	19.50	2.135	10.68	12.91
Sulfur Dioxide (SO_2)	0.003	0.02	0.03	0.003	0.02	0.03
Nitrogen (N_2)	8.814	61.18	80.47	13.221	66.16	79.99
Oxygen (O_2)	0.00	0.00	0.00	1.168	5.84	7.07
Total	14.407	100.00	100.00	19.982	100.00	100.00
Average Molecular Wt.			28.00			28.21
Air Requirement			321.0 lb			481.5 lb
Flue Gas Weight			403.40 lb			563.69 lb

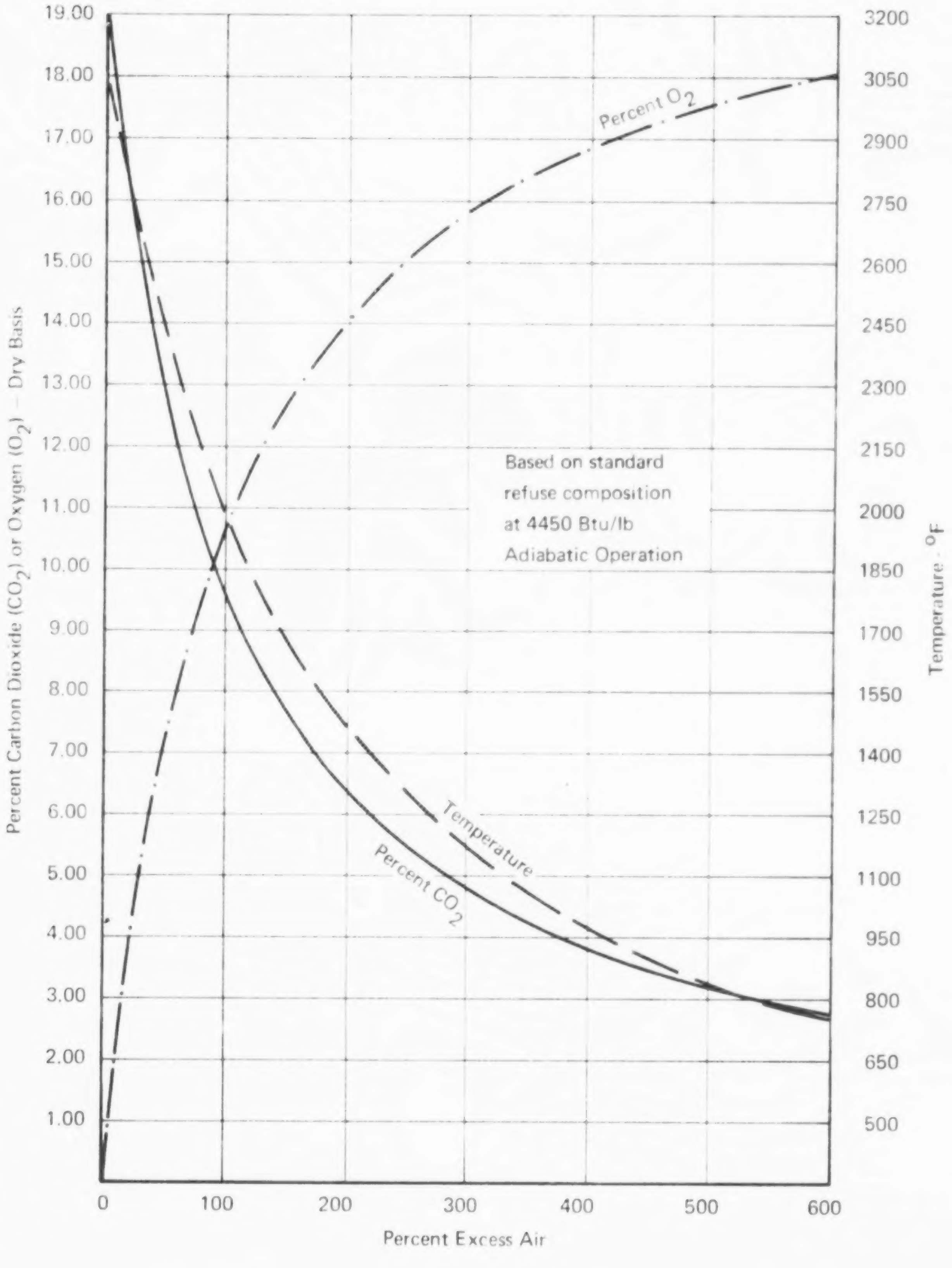


FIGURE C–1 FLUE GAS ANALYSIS AND TEMPERATURE RELATIONSHIPS

APPENDIX D

INCINERATOR QUESTIONNAIRE

APPENDIX D

INCINERATOR QUESTIONNAIRE

The U.S. "Incineration Industry" is poorly defined in the literature in terms of both design features and the operating practices of the various plants throughout the country. In order to provide a data base to support our analysis of the industry, a questionnaire was prepared and mailed to all identified incinerator plants. The questionnaire consisted of two parts: a sheet asking specific questions regarding the units and a diagram showing the general layout of the plant with requests for various operating and design data. This Appendix includes a photo-reduced copy of the question sheet and a representative diagram data sheet.

Code No

(Please answer as many questions as you can.)

OPERATION OF MAJOR MUNICIPAL INCINERATORS IN THE UNITED STATES

1. When was your unit built? ______ and when likely to be replaced? ______

2. Who was the consulting engineering firm for your unit? ______

the construction firm? ______

3. Is the amount of refuse delivered increasing? ☐ or decreasing? ☐

4. Where does your refuse come from? Residential ______ % (Population ______)

Commercial & Industrial ______ %

5. What is the approximate make up of your refuse?

Combustible trash (paper, plastics, etc) ______ %
Non Combustibles (metal, glass, etc.) ______ %
Garbage ______ %
Leaves, brush, etc ______ %
Other major items such as ______ ______ %
Approx. moisture content of average load ______ %

(Say Which)
% by Volume ☐
or
% by Weight ☐

6. Is there any refuse you do not accept for burning? Yes ☐ No ☐

If yes, what kinds? ______

______

7. Do you have an especially busy time of day, week, and/or year? (Answer for all three categories)

	Yes	No	When?	What % Over Normal	What causes it? (Especially if one type of refuse becomes more important) Extra Garbage	Extra Garden Waste	Other
day	☐	☐	______	______	☐	☐	☐ ______
week	☐	☐			☐	☐	☐
year	☐	☐			☐	☐	☐

8. How do you judge proper operation? (Check all that apply)

Temperature ☐ Where in furnace? ______
Other ☐ (Specify) ______
Residue quality ☐

9. How do you adjust your unit for proper operation? (Check all that are regularly used)

Vary feeding rate ☐ Vary underfire air ☐ Vary overfire air ☐

Other ☐ ______

10. What is the usual ratio of underfire air to overfire air volume? ______

11. What equipment changes would improve your operation? ______

______

______

12. Do you have much of a slagging problem? Yes ☐ No ☐ If so, where in the furnace? ______

______ How cured? ______

FILL IN BOTH SIDES

(continued)

13 What air pollution control equipment is in operation? (Check all that apply)

		Type (if known)	Manufacturer (if known)
☐	Wet scrubber	____	____
☐	Settling chamber	____	____
☐	Mechanical (cyclone)	Dry ☐ Wet ☐ Diameter ____ inches	____
☐	Other	____	____
☐	Wetted baffles	Refractory ☐ Metal ☐	(Sketch plan view below to show size, shape and spacings)

14 Is the air pollution control equipment effective? ____

15 How do you judge performance of the air pollution control equipment? ____

____

16 Was your unit ever performance tested	Yes	No	By whom?
a) for capacity?	☐	☐	____
			Year ____
b) for air pollution emissions?	☐	☐	____
			Year ____

17 Operating personnel (crew/shift) Men ____ + foremen ____

Average years employed ____

Number of months to train ____

Is there a formal training program? Yes ☐ No ☐

18 Availability of new men Readily ☐ Fair ☐ With difficulty ☐

19 How often do you repair or replace the following

Linings ____

Instruments ____

Grate Parts ____

Air Pollution Control Equipment ____

Other Mechanical Parts ____

Other (specify) ____

____

20 What plans for increasing plant capacity, if any ____

____

21 Plans for adding improvements? What items? ____

____

22 Is use being made of any by products, such as

Heat (steam)? ☐ Scrap metal? ☐ Other ____

Have you filled in both sides and marked the applicable diagram? Thank you for your help.

Rated Capacity __________ Tons Per 24 Hour Day

Actual Throughput __________ Tons Per 24 Hour Day

Operation __________ Hours Per Day
__________ Days Per Week

______ Percent Downtime for Maintenance

Primary Chamber

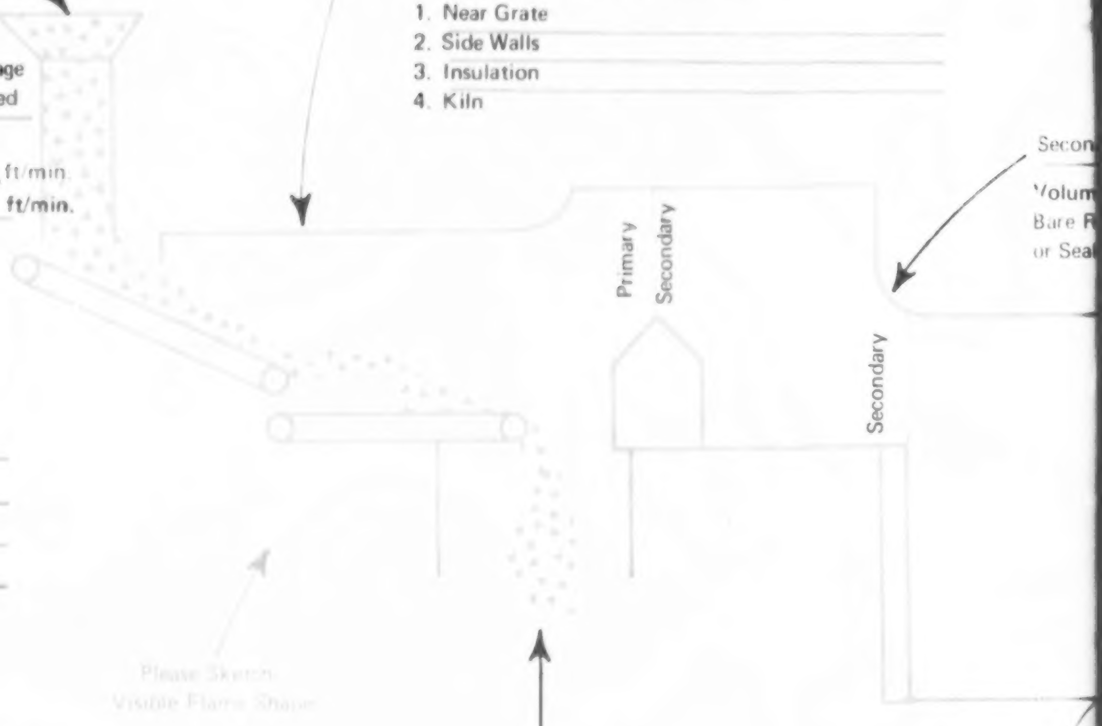
Length ________ Feet ________
Width ________ Feet ________
Volume ________ Feet^3 ________

Bare Refractory ☐
or Sealed Walls ☐

Refractory (Type & Thickness)

1. Near Grate ____________
2. Side Walls ____________
3. Insulation ____________
4. Kiln ____________

Grate	Width	Length	Average Speed
Number 1	_____ feet	_______ feet	_____ ft/min.
Number 2	_____ feet	_____ feet	_____ ft/min.



Secon
Volum
Bare R
or Sea

D
W

Grate Type, Manufacturer

____
____
____
____

Estimated Average
Depth of Refuse Bed

At Feed Arch __________ Feet
At End First Grate __________ Feet
At End Second Grate __________ Feet
____
At (Other) __________ Feet

Burn Out Quality

Excellent ☐
Moderate ☐
Fair ☐
Poor ☐
Percent Combustible ______ %

Temperatures

Please mark on sketch with a circle (①) to show where temperature is measured.

Point	Average	Maximum	Minimum
①	______ °F	______ °F	______ °F
②	______ °F	______ °F	______ °F
③	______ °F	______ °F	______ °F
④	______ °F	______ °F	______ °F
⑤	______ °F	______ °F	______ °F
Stack	______ °F	______ °F	______ °F

Air System { Please Comment on Back Side if Required

Please mark on sketch with an arrow or a circle (⊗ means flow through near wall, ⊙ means flow through far wall) where underfire and overfire air enter the furnace. If known, please note CFM and air temperature on arrow or beside circle. Please sketch size and shape of overfire air ports on back of this sheet.

Please note forced draft fan horsepower and rated cfm.

Please fill out this sheet as completely as possible and return with the questionnaire.

Code No. ________

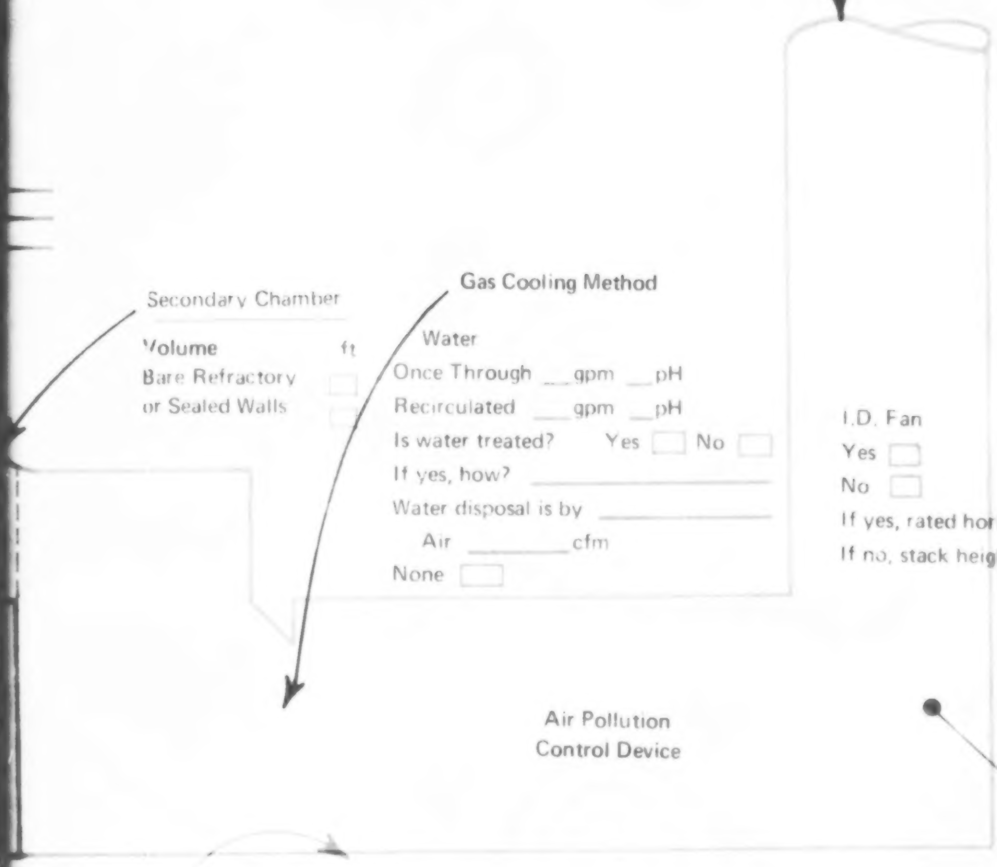
If Known

________ Percent Oxygen (Average)

________ Percent Carbon Dioxide (Average)

TRAVELING GRATE DESIGN

NO. 2



Secondary Chamber

Volume ft

Bare Refractory ☐

or Sealed Walls ☐

Gas Cooling Method

Water

Once Through ___gpm ___pH

Recirculated ___gpm ___pH

Is water treated? Yes ☐ No ☐

If yes, how? ________________

Water disposal is by ________________

Air ________ cfm

None ☐

I.D. Fan

Yes ☐

No ☐

If yes, rated horsepower ____and ___cfm at ____°F

If no, stack height ____ft. above ground

____ft. above primary chamber

Air Pollution Control Device

Dry Bottom ☐

Wet Bottom ☐

%

Smoke Alarm

Not Installed ☐

Not Operating ☐

Frequency ________Per Day

Is alarm set off or extra-heavy smoking observed as a result of any known condition?

Start-Up ☐ Shutdown ☐

Wet Refuse ☐ Charging ☐

Other ________________

____

____

Draft { Please mark on sketch with a triangle (⚠) showing where pressure is measured.

Point	Location	Average Value
1	________________	________ in water.
2	________________	________ in water.
3	________________	________ in water.
4	________________	________ in water.
5	________________	________ in water.
6	________________	________ in water.

APPENDIX E

OPERATING EXPERIENCE ON EUROPEAN ELECTROSTATIC PRECIPITATORS

APPENDIX E

OPERATING EXPERIENCE ON EUROPEAN ELECTROSTATIC PRECIPITATORS

At the present time, U.S. operating experience with electrostatic precipitators on municipal incinerators is limited to several short-term pilot test programs. Because of the unique chemical nature of incinerator flue gases and particulate with respect to corrosion and abrasiveness, information on operating problems was solicited from the plant superintendents of five European incinerators. The following summarizes their comments.

A. DÜSSELDORF, WEST GERMANY

Mr. Thoemen, Plant Superintendent, advised that there was a 1 1/2-year delay in the completion of this plant due to public objection in the area of the plant. Since completion, there have been no complaints.

No specific record is kept of maintenance man-hours, but maintenance is reportedly negligible. The precipitators are considered very dependable in service, and non-scheduled outages of the equipment are virtually unknown. The precipitators are normally inspected and preventative maintenance performed during plant shutdowns.

Some maintenance was done on the rappers after two years of operation. No discharge electrode failures have been experienced. No corrosion has been found. Dust removal was a problem initially, reportedly because the original pneumatic conveying system was inadequately sized. Modifications were made, including building screw conveyors into the precipitator trough hoppers, enlarging the discharge openings, and installing special-type rotary discharge valves.

Mr. Thoemen mentioned that during 1968 the plant generated 390,000 tons of steam from 256,000 tons of refuse. The sale of the steam covered 86% of the operational and maintenance cost, while 13% return resulted from the sale of scrap and 1% on the sale of ash.

B. MUNICH POWER PLANT, NORTH MUNICH, WEST GERMANY

Mr. Baumeister, Assistant Plant Manager, was interviewed on April 10, 1969. He reported that the first furnace was placed in service in 1963, and the first general inspection of the system occurred in 1966. Up to that time, there had been 10,000 running hours on the furnaces and they had had 178 normal shutdowns (not for repairs). The second general inspection was in progress at the time of this visit, and 24,000 hours running time and 610 normal shutdowns were recorded in the 1966-1969 period.

An inspection of the #1 and #2 furnace precipitators was in progress at the time of this visit, and the general condition of the units was found to be excellent. No evidence of corrosion of the casing or internals was found. No discharge electrode failure had been experienced since the start of operation in 1963. During the 1966 outage, the wear surface on the discharge electrode rapping system had been replaced and the collecting surface rapper shaft bearings had been serviced.

The gas cleaning system was described as being very dependable in operation, with low maintenance requirements. (No specific maintenance man-hours are logged, but Mr. Baumeister considered them negligible.) The dust removal system as originally installed caused some trouble, and the rotary valves which had been installed originally were replaced.

No refuse analysis was available. It was mentioned that the lower heat value of their refuse is in the range of 1100 to 1500 kcals/kg.

C. ISSY LES MOULINEAUX, PARIS, FRANCE

The Director of the plant reported that since startup in 1965, the plant has had very little trouble with the electrostatic precipitators and the efficiency has consistently been very good. At the time of this visit, it was observed that the effluent from the stack was visible, and this was contrary to previous reports and photographs. It was explained that due to waste heat boiler tube corrosion problems, a castable refractory had been applied to the lower portion of the boiler tube walls. This resulted in a substantial increase in the flue gas temperatures – from 250°C to 350°C. This temperature increase, of course, resulted in a volume increase at the precipitators of about 25%, which caused the stack discharge to become visible. The high temperature also caused some seizure of precipitator rapping mechanisms (since they are not designed for high-temperature operation). Boiler modifications will be implemented in 1970 to restore normal temperature conditions.

Although no man-hour records are kept on the gas cleaning system as a separate entity, the Director stated that there has been little maintenance required. In the four years of operation, only one discharge electrode has failed in the eight precipitators. There has been no evidence of corrosion. The plant runs continuously with only a once-a-year period of general inspection and maintenance (3 weeks in August). Intermittent outages may be required if emergency repairs are necessary. Since 1965, the operating times of the four furnaces have been:

#1 Furnace – 27,000 hours
#2 Furnace – 26,000 hours
#3 Furnace – 35,000 hours
#4 Furnace – 25,000 hours

The plant has not experienced trouble with precipitator hopper pluggage. The dust removal system is of a dry, pneumatic type. Early problems were experienced due to inadequate capacity of the pneumatic system. The capacity was then doubled, and there have been no problems since.

D. TOURCOING, FRANCE

At the time of this visit, the gas cleaning system had been in service two years. The Director stated that the performance has been good despite the fact that the system is often overloaded. The plant has reportedly had no problems with precipitators and no parts replacement in the two-year period. No discharge electrodes have failed, and no evidence of corrosion has been found. The plant is in operation 24 hours a day, six days per week. The precipitators exceeded the original guarantee based on the official government tests, and stack appearance and lack of complaints indicate that the guaranteed performance level is being maintained.

The gas cooling system gave some trouble as originally installed, in that the high-pressure water sprays were impinging on the furnace walls, not evaporating the water completely, and causing water runoff and a "muddy" condition. Reduction in number of sprays and relocation of sprays has since solved this problem, and the hopper under the spray area is now dry. The air dilution, water spray control system functions very well and maintains proper temperature at the precipitator inlet.

The dry dust removal system has not given them any trouble, although an attempt to handle the dust in a slurry state was not successful.

E. CASTLE BROMWICH, BIRMINGHAM, ENGLAND

Plant personnel expressed general satisfaction with the day-to-day efficiency of the gas cleaning system. During the visit, the stack was observed to be free of visible effluent. The plant was placed in service in 1966, and despite the close proximity to modern apartment buildings, it was reported that no complaints have resulted from the operation of the plant nor from air pollution.

The gas cleaning system may be divided into three basic categories – gas cooling tower, precipitator and dust removal system. Comments of plant personnel on the operation and maintenance of each were as follows.

1. Gas Cooling Tower

The gas cooling tower has been a continual source of trouble since startup. This is an upflow arrangement, with the sprays at the bottom of the tower.

Originally, the sprays were oriented, and sprayed against the gas flow, and pluggage and corrosion were experienced. The nozzles were then turned to spray concurrent with the gas flow, and shields were also provided for the nozzles. These modifications improved spray dependability; but moisture carryover continues to be a problem, causing wet accumulations of ash at the inlet (bottom) and outlet (top) of the tower. This necessitates weekly cleaning of these areas. The wetness carries over to the precipitator inlet gas distribution plate but is not evident in the precipitator itself. The sprays provided for intermittent wash-down of the tower walls were found to be ineffective and were removed. The tower does an adequate job of cooling and controlling gas temperatures despite these problems, but a nearby plant at Sutton-Coulfield (which was placed in service very recently) has a larger, downflow-type evaporation cooling tower which should not have the same deficiencies. Twelve man-hours are spent per week cleaning the tower inlet and outlet. Serious corrosion has been found at the tower outlet throat.

2. Precipitator

Very little maintenance has been found necessary on the precipitator during the two years of service. The plant has a five- to six-week annual outage, and seven man-days are spent per year on routine maintenance and inspection. To date, no failure of discharge electrodes has been experienced. Rapping system maintenance has consisted of changing the drive shaft support bearings once. Minor corrosion has been found around the precipitator access doors. Availability was considered "excellent," although no actual record is kept. In the past six months, three discharge electrode system suspension insulators failed. The cause of the failure had not been determined.

3. Dust Removal System

Dust removal has been a problem due to pluggage, but this may be related to moisture carryover from the tower. The original 6" rotary discharge valves were enlarged to 12" discharging into a slurry system. The system is still not satisfactory, and there are plans to replace the slurry system with a pugging device which will discharge the dust directly into removal boxes.

Despite the experiences related, the plant personnel look upon the installation favorably particularly since it was the first such system in the United Kingdom. Necessary improvements were reflected in their second plant (Sutton-Coulfield).

APPENDIX F

BY-PRODUCT RECOVERY

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APPENDIX F

BY-PRODUCT RECOVERY

A. PAPER RECOVERY

1. U. S. Waste Paper Recovery Markets

a. Present

The forecast U.S. consumption of paper and paperboard for 1969 is 56 million tons.[1]* Of this quantity, approximately 10 million tons (or 18% of the paper materials consumed) will be reclaimed and recycled as feed for future paper production. For the past 15-20 years, the quantity of reused paper has remained at the relatively constant level of 9 to 10 million tons annually. Total paper consumption, however, has not remained constant but has kept pace with the economy, growing at an average annual rate of approximately 4% per year since 1947. The primary factor stifling the growth of recycle paper has been one of economics.

Of the 10 million tons of waste paper or paper stock recycled annually, approximately 70%, or 7 million tons of bulk grade, consists of newspaper and corrugated paper. The remaining 30% (3 million tons) is:

- bleached foodboard and other white cuttings requiring very little preprocessing other than defibering. This material is primarily utilized as a substitute for virgin pulp.

- Heavy books and ledgers processed by de-inking. Magazine stocks which were once a major de-inking item are no longer recovered due to the increasing quantities of adhesives, fillers, and other contaminants which adversely affect the economics of de-inking.

b. Future

The pattern of significant growth in paper and paperboard consumption with little or no growth in the quantity of paper recovered may be expected to continue through 1975,[1] reflecting the expanding utilization of virgin wood pulp as a fiber source. After 1975, however, this trend may change. The demand for paper and paper products will continue, but the quantity of virgin pulp available and the difficulties in obtaining new mill sites should increase the price of wood pulp and favorably affect the economics of waste paper recovery. As a result, the late 1970's or the early 1980's should see an increase in the use of waste paper as a feed material for paper and paperboard production.

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*All superscript numbers refer to the list of references (Section D) at the end of this appendix.

The American Paper Institute has estimated that reasonable utilization of reused paper might grow from 12 million tons in 1975 to 25 million tons in the '80's. Paper and paperboard consumption during this period will be near 80 million tons annually.[1]

2. Economics of Paper Recovery

Present scrap paper prices range between $8 and $16 per ton. The specific value depends upon such factors as the following:

- The grade of the paper.
- The amount of contamination present.
- The presence of additives such as inks, lacquers, and adhesives.
- Geographical location.

Table F-1 summarizes some of the market prices for selected paper stock grades in 1967. These prices are variable, however, and local outlets must be explored.

As may be inferred from above, the degree of contamination of waste paper significantly effects the economics of paper recycle. Contaminated paper such as might be found at an incinerator site, either on delivery or after dumping into the storage pit, would not generally be considered desirable for reuse given existing technology and economics.

Assuming, however, that a market exists for salvaged paper in refuse and that approximately ½ to ¾ tons of paper could be hand-sorted from refuse in one hour,[2] such recovery operations would incur a labor cost of $4 to $6 per ton of paper collected (at $3/hr wages). In addition, other costs would be incurred in the investment in equipment, such as storage bins and baling equipment, and in the transportation of the reused paper. If the market yields an average price per ton of from $8 to $16 for such paper, some profits might be expected. It is doubtful, however, that $8 to $16 per ton could be obtained for the relatively contaminated paper found at incinerator sites. In addition, any profits would be short-lived if recovery of paper from municipal refuse was practiced on a large

TABLE F-1

SELECTED SECONDARY FIBER USAGE, PAPER STOCK GRADES, SPECIFICATIONS, AND RECENT MARKET PRICES[2] *

Grade Description and Specifications	Market Price Jan. 20, 1967 ($/ton)
No. 1 - Mixed Paper	
Consists of a mixture of various qualities of paper, packed in bales weighing not less than 500 lb and containing less than 25% of soft stocks such as newspapers. Prohibitive materials may not exceed . . . . 1% Total out-throws may not exceed 5%	$8.00-$9.00 (New York)
Super Mixed Paper	
Consists of a clean sorted mixture of various qualities of papers, packed in machine-compressed bales not less than 60 inches in length and containing less than 10% of soft stocks such as newspapers. Prohibitive materials may not exceed . . . . 0.5% Total out-throws may not exceed 3%	$11.00-$13.00 (Chicago)
No. 1 - News	
Consists of newspapers packed in bales of not less than 54 inches in length, containing less than 5% of other papers. Prohibitive materials may not exceed . . . . 0.5% Total out-throws may not exceed 2%	$15.00-$16.00 (New York)
Super News	
Consists of sorted fresh newspapers, not sunburned, packed in bales of not less than 60 inches in length, free from papers other then news and containing not more than the normal percentage of rotogravure and colored sections Prohibitive materials . . . . None permitted Total out-throws may not exceed 2%	$18.00-$20.00

* See Section D, References

TABLE F-1 (Continued)

Grade Description and Specifications		Market Price Jan. 20, 1967 ($/ton)
Over-Issue News		
Consists of unused overrun regular newspapers printed on newsprint, baled or securely tied in bundles, and shall contain not more than the normal percentage of rotogravure and colored sections		$22.00-$23.00 (New York)
Prohibitive materials . . . . None permitted		
Corrugated Containers		
Consists of corrugated containers having liners of either jute or kraft, packed in bales of not less than 54 inches in length.		$16.00-$18.00 (New York)
Prohibitive materials may not exceed	1%	
Total out-throws may not exceed	5%	

Grade Definitions: The grade definitions described are definitions intended to define grades as they should be packed and graded. *Consideration should be given to the fact that paper stock as such is a secondary material produced manually and may not be technically perfect.*

Out-throws: The term "out-throws" is defined as "all papers that are so manufactured or treated or are in such a form as to be unsuitable for consumption as the grade specified." The maximum quantity of "out-throws" indicated in connection with the above grade definitions is understood to be the total of "out-throws" and "prohibitive materials."

Prohibitive Materials: The term "prohibitive materials" is defined as:

(1) any materials which, by their presence in a packing of paper stock in excess of the amount allowed, will make the packing unusable as the grade specified;

(2) any materials that may be damaging to equipment.

scale. The total supply of newsprint in collected municipal refuse is significantly larger than the 7 million tons of total recycled newsprint demanded annually. As a result, local markets could be readily saturated if paper recovery was practiced widely. It should also be recognized that a significant portion of the local waste paper market is already served by private waste collection companies. In many cases, the relatively clean office and commercial waste paper handled by these companies (and the correspondingly lower recovery treatment costs) would assure them a strong position in the already-small waste paper market. This unbalanced supply-demand relationship would significantly reduce profits.

B. METAL RECOVERY

1. U. S. Metal Recovery Markets

a. Present

Metal salvage is presently being carried out throughout the country at composting facilities, at eleven municipal incinerator facilities, and at two private incinerators. The annual average metal content of municipal refuse is approximately 8% (see Chapter IV). However, refuse metal content has been reported to range from about 5% to 15% at different locations. Metal cans, primarily composed of ferrous metals – aluminum and tin – account for an estimated 58% of this metal fraction. Approximately 50%, or about 4% of the total refuse, appears as steel in cans.

This figure agrees well with a study performed on a plant in Atlanta, Georgia, in 1966, which reported metal can recovery (by magnetic separation of shredded metal residue) of approximately 3.8% of the refuse consumed. At the levels indicated above, somewhat more than 6 million tons of ferrous metal from cans is potentially available in collected municipal refuse, with about one-half of this quantity appearing in the urban areas where salvage could be carried out on an economical scale.

There are potentially three major uses for metal cans in refuse:

- As precipitation iron in the beneficiation of copper ore.
- As a source of tin through chemical de-tinning.
- As a source of steel scrap in steel-making.

The refining of copper ore is by far the most significant market for scrap metal in refuse. The tin plate and other contaminants in refuse scrap metal make this source less desirable for steel-making than the relatively contaminant-free quantities of scrap steel supply available from other sources. De-tinning plants are currently in operation, but their requirements for only clean scrap, such as is found in can manufacturing plants, make metal cans in refuse an unacceptable feed material.

In the refining of copper ores, the ferrous metal from refuse is utilized in a leaching process which results in the precipitation of copper. The ore is dumped on large piles of this salvaged ferrous metal, and a 5-10% solution of sulfuric acid is percolated through the bed. The ore reacts with the sulfuric acid to form copper sulfate. When the copper sulfate solution reaches the salvaged metal, ferrous sulfate is formed and metallic copper is precipitated. The precipitated copper is washed off and sent to the smelting operation.

The market for salvaged ferrous metal for copper recovery was approximately 250,000 tons in 1966, with estimates of 500,000 tons as the maximum potential consumption. The previous estimate of over 6 million tons of ferrous metal available from metal cans in refuse suggests that this supply far exceeds the potential demand. In addition, transportation charges rapidly degrade recovery economics if the salvage plant is located at long distances from the copper refining sites.

b. Future

The quantity of ferrous metals used in can manufacturing is expected to remain relatively constant or to drop off slightly in the future. In addition, the use of aluminum in cans is expected to rise significantly. These trends suggest that the percent of ferrous metals in refuse will decrease and that ferrous metal salvage from municipal refuse may become less economical. Selective recovery of aluminum, brass, and other metals will probably also be uneconomical because of their low concentration in refuse.

2. Metal Recovery Methods

Most metal reclamation systems applied to municipal refuse salvage ferrous metals from incinerator residue. The only proven technique of segregating metal prior to incineration is by the use of manual labor. This process is extremely labor-sensitive and depends upon the available costs of labor. On the other hand, salvage equipment following the incineration systems has several distinct advantages:

- The combustible fraction of material mechanically bound or ensnarled in the metal is removed by incineration.

- With most combustible materials removed, the incinerator residue is cleaner and more psychologically desirable to handle than raw refuse.

- A portion of the tin coating on cans will have oxidized and flaked off during incineration.

- The volume of materials in the residue is substantially reduced relative to the refuse feed, reducing the required size of salvage equipment.

- Any failures or breakdown in the salvage equipment does not effect the incineration equipment upstream.

The first step in salvaging metal from incinerator residue involves cleaning the residue with rotating cylindrical screens. Here, the nonmetallic ash is washed from the cans and discharged through the screen surface and collected in residue trucks. Constant inspection of the residue materials passing to these rotary screens is necessary to insure that such items as wire, heavy metal, and masonry which might foul the screens, interfere with operations downstream, or contaminate the product are removed. Also, unburned materials such as paper and large logs which remain after incineration and which might cause difficulties downstream may also be removed.

The washed metals, consisting primarily of cans, are discharged from the outlet of the rotary screen washers into a drag conveyor where the cans are elevated and transferred to a large collection hopper. The hopper is usually sized to permit operation of the metal reclamation equipment during the first shift only. The metal from the incineration system during second and third shift operation is stored in this bin for treatment on the following day.

The material from the bin is fed to a conveyor which in turn feeds a continuous can shredder. The shredder has rotating hammers that tear the cans by impact. These shredded materials are discharged to a grate which controls product size to the desired range. The shredded material than passes through a magnetic separator which segregates the ferrous material from the nonmagnetic metals. The magnetic material is then transported by conveyor to a collection bin for subsequent feeding to a transportation vehicle. This final processing is usually done in one shift per day.

3. Economics of Metal Recovery

The economics of metal salvage is dependent upon four basic criteria:

- The capital investment for the salvage equipment.
- The operating costs for this equipment.
- The shipping costs of the collected metal.
- The market prices for this salvage metal.

a. Capital Investment

Metal salvage equipment is now installed in 13 refuse incineration facilities, as well as the majority of composting facilities throughout the country. Two municipal incinerator installations are presently closed down because of lack of markets for their product. Table F-2[2] summarizes available investment data for those municipal incinerator installations utilizing metals salvage equipment. These data suggest that investment costs for metal salvage equipment vary from $350 to $540 for each ton per day of refuse burning capacity (scaled to mid-1969 costs). The lower costs represent systems which do not have facilities for washing or shredding of the metal. In addition, the estimated investment costs for metal recovery equipment in a proposed 800 ton per day incineration facility in Washington, D.C. was $400,000 or approximately $500 for each ton per day.[4] In all cases, this equipment is representative of systems that salvage metal from incinerator residue; not from raw refuse.

b. Operating Costs for Metal Recovery

The above-mentioned study[4] examining the feasibility of salvaging metal in an 800-ton-per-day incineration facility located in Washington, D.C. estimated that the annual operating expenses for such a metal recovery system would be approximately $99,350. This annual total is composed of:

- Labor costs at approximately $36,850.

- Maintenance at $8,400.

- Electric power at $3,500.

- Annual fixed charge (10-year amortization at 4-1/2% interest) at $50,600.

TABLE F-2

THIRTEEN MUNICIPAL INCINERATORS PRACTICING METAL SALVAGE – 1968[c]

Location	Plant	Year Built	Capacity (tons/day)[b]	Revenue from Cans ($/ton of Metal Sold)[b]	Capital Cost of Metal Salvage Equipment Adjusted to 1969 Costs
Atlanta, Georgia	Mayson	1939 and 1952	700[5,6]	17.58[4]	
Atlanta, Georgia	Hartsfield	1963	500[4,6]	17.58[4]	$270,000 ($540/TPD)
Louisville, Ky.	–	1957	1,000[4]	15.82[4]	–
Chicago, Illinois	Southwest	1963	1,200[4,5]	11.23[4]	–
Chicago, Illinois	Stickney (private)	1958	–	–	–
Chicago, Illinois	Boda (private)	–	–	–	–
Chicago, Illinois	Medill	1956	780[4]	11.23[4]	–
Chicago, Illinois	Calumet	1959	1,200[4]	11.23[4]	–
Broward County, Florida[a]	No. 1	1964	150[4]	–	52,000 ($350/TPD)
Broward County, Florida[a]	No. 2	1964	150[4]	–	53,000 ($250/TPD)
Tampa, Florida	–	1967	–	–	– (350/TPD)
Dayton, Ohio	Montgomery County	1967	–	–	–
DeKalb County, Georgia	–	1967	–	–	–

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a. Currently metal salvage not being practiced due to lack of market for product; no provision at these plants for washing or shredding of cans.

b. Superscript numbers refer to list of references in Section D.

c. **Source:** References 2, 4, 5, 6.

Using a conservative figure of 3-1/2% by weight of ferrous metals in refuse, approximately 28 tons of shredded metal can be obtained per day for an 800-ton-per-day facility operating three shifts per day. This results in an annual production of approximately 7,000 tons (for 250 days per year operation) or approximately $14 per ton of salvaged metal.

c. Shipping Costs and the Market Price for Salvage Metal

Most municipal refuse facilities utilizing metal salvage equipment sell their collected metals at $10-20/ton to scrap metal firms specializing in this type of metal. These prices, however, have been continually decreasing over the past several years. For example, in 1956, shredded metal could be sold for $27/ton f.o.b. Atlanta. By 1966, however, this price had declined to $15/ton.

As mentioned earlier, the primary market for this salvage metal is in the refining of copper ores. These copper mines are primarily located in the southwestern part of the U.S. and in Mexico. A significant factor, therefore, in the economics of metal recovery, is the shipping cost associated with the transportation to the copper mines. In order to reduce shipping costs, the shredded metal (with a density of only 20-25 lb/cu ft) is often baled, increasing the bulk density to about 150 lb/cu ft. It has been estimated that shipping costs of salvage metal from Washington to copper mines in Utah or Arizona would be about $83/ton. With $75/ton the estimated top price being paid by copper mines in southwestern United States, metal salvage on the northeast coast and in the middle atlantic states does not appear to offer much economic incentive.

C. HEAT RECOVERY

1. Introduction

The recovery of heat in incinerators is accomplished by transferring the energy released in the combustion of refuse to water for the production of steam:

- by radiant transfer of energy in the primary chamber; and/or
- by convective transfer of the sensible heat in the flue gas.

The waterwall boiler concept employs both methods. Energy is transferred to the waterwall tubes in the primary chamber, primarily by radiant exchange with the burning bed and by gas radiation from the overfire volume. Flame temperatures above 2000°F and low excess air operation (high CO_2 and H_2O concentrations) significantly enhance the efficiency of this radiant energy transfer. In addition, banks of superheater and convective tubes located in the flues following the primary chamber capture the sensible heat from the flue gas stream.

Economizers can also be utilized in conjunction with these convection tube banks for feedwater heating. A description of the waterwall boiler concept and a presentation of the investment and operating economics of such systems are presented in Section VII.D.

Convective boilers located in the flues downstream of the primary chamber can be utilized in conjunction with conventional refractory grate furnaces. The sensible heat in the flue gases of such systems is transferred by convection to these watertubes to generate steam. Economizers can also be used. The technical and economic aspects of convection boiler systems are presented in Section VII.D. and Appendix B.

The paragraphs below provide the following additional information necessary to complete the economic evaluation of boiler systems:

- The quantity of steam generated per pound of refuse burned.
- The range of steam by-product credits which can be expected.

The following section will discuss the parameters affecting steam generation capacity. Such information as the effects of refuse moisture and incinerator excess air on the steam generating capacity will be considered for both conventional refractory systems employing convective boilers as well as waterwall incineration systems. Section 3 will present values for steam generation capacity, as well as steam credits in municipal incinerators either on-stream or under construction. These values will be based on actual plant performance within the U.S. and Canada.

2. Parameters Affecting Steam Generation Capacity

In a recent report to the government of Washington, D.C.,[3] the factors which affect steam generating capacity are discussed in some detail. Two factors are of primary importance:

- The moisture content of refuse as it affects the heat release value (Btu/lb of refuse).
- The excess air utilized.

In addition to the effect of variations in refuse heat content caused by changes in refuse composition (i.e., the fractional contributions of paper, yard wastes, food wastes, etc.), the effect of total moisture content on steam generation rate is extremely significant. Such variable and uncontrollable factors as rain, drying winds, and the storage history of the refuse prior to being delivered to the incinerator site affect moisture content and thus steam-raising potential of the plant. Moisture may occasionally be added to the refuse in the storage pit to alleviate dusting problems. For these reasons, combined firing of fossil fuels with the refuse may be desirable to assure reliable steam generating capability. Figure F-1,[3] an energy balance around the incinerator, shows the effects of the refuse moisture content on steam generation rate.

Also illustrated in Figure F-1 are the effects of excess air on the steam generation rate. Because refractory furnaces generally operate at excess air levels of 150-200%, they have a lower steam-raising potential than waterwall systems which operate at 80-100% excess air levels. Since for actual boiler outlet temperatures differ for varying boiler designs, Figure F-1 should only be utilized to illustrate the *relative* differences in steam-generating capacity between waterwall and convective boiler systems.

The effect of excess air on steaming rate is important in incinerator practice because of anticipated variation of instantaneous excess air levels. For example, in conventional incinerators, overfire air rates are generally held fairly constant. However, underfire air rates vary according to the resistance to flow through the grate and refuse bed. In response to variations in refuse bed density, porosity, and height, underfire air rates will change. Since the majority of the total air to the incineration system is generally undergrate air, these variations will affect the instantaneous steam generation rate, as indicated in Figure F-1. For example, consider refuse which has an average moisture content of approximately 28%. An increase of 20% in air flow (from 150% to 200% excess air) for a conventional refractory system employing a convective waste heat boiler would reduce the steam-generating rate by approximately 13% (from 1.5 to 1.3 lb of steam per lb of refuse). For a waterwall system, an increase of 25% in air flow (from 60% to 100% excess air) for 28% moisture refuse would decrease the steam-generating capacity of the system by approximately 10% (from 2.5 to 2.25 lb of steam per lb of the refuse). While savings in air flow of these magnitudes is not expected, some perturbations in steaming rate from this cause can be expected. This problem, as discussed above for moisture variation effects, enhances the attractiveness of combined firing to obtain stable steaming rates. The combined firing concept is now under study by the National Air Pollution Control Administration.

As a result of this variability in refuse steam generating rate, together with irregular variations in refuse moisture content, the most practical installation of an incinerator boiler might be as part of a larger system where waste heat recovery contributes a relatively small portion of the total steam consumed. Under these conditions, the instantaneous variations in steam-generating capacity will not significantly affect the total system. Also, the conventional boiler systems utilized in conjunction with the waste heat incinerator(s) could be called upon to carry part or even all of the steam load from the waste heat boiler in case of incinerator shutdown.

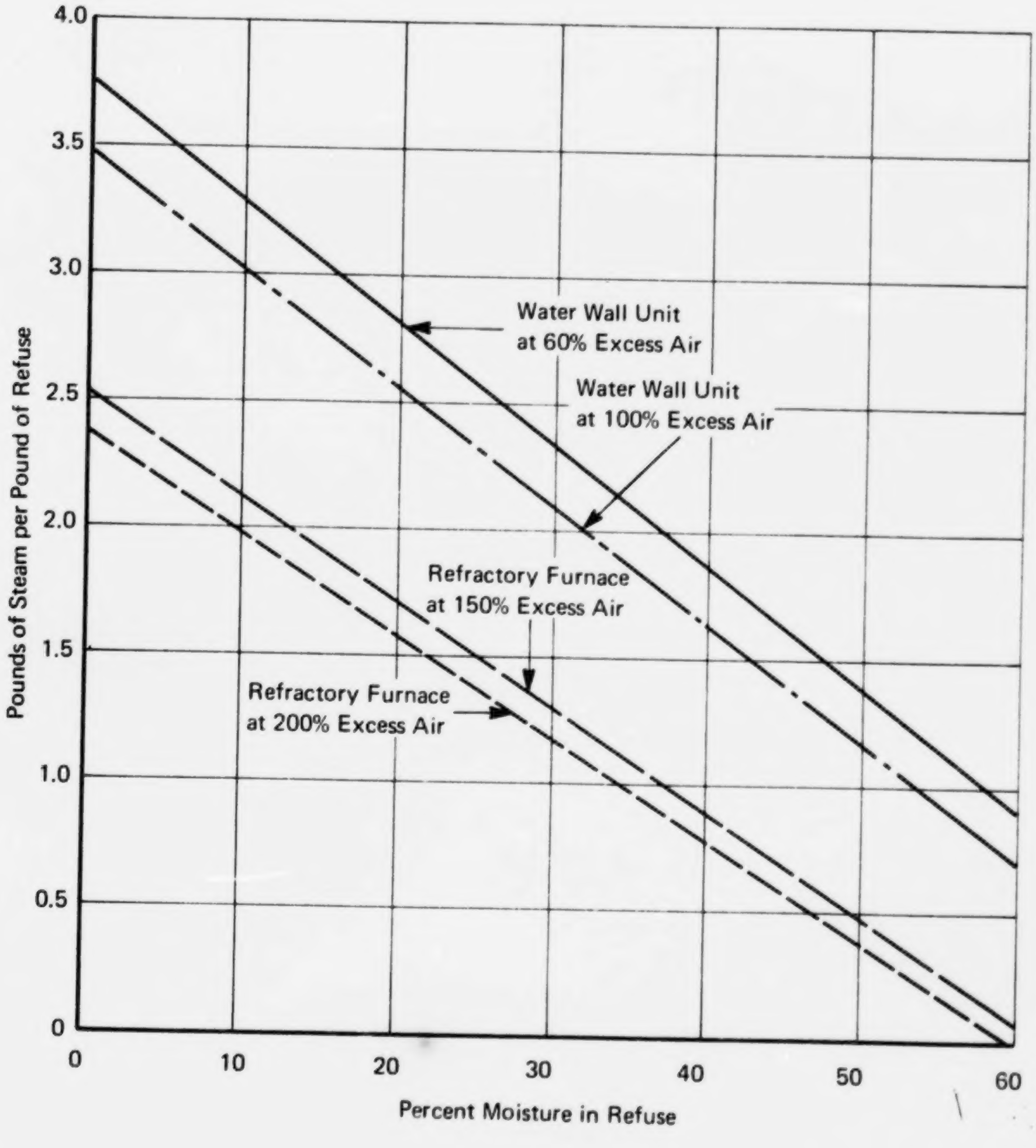

FIGURE F–1 EFFECTS OF RESIDUE MOISTURE AND EXCESS AIR ON STEAM GENERATING CAPACITY

Source: Reference 3

3. Steam Generation Capacities and Steam Credits for Existing Systems

Table F-3 shows the values for steam generation capacity and steam credits for various incinerator installations in the United States and Canada. Values for European installations are not presented because their refuse heat content and steam price structure are significantly different from those in the United States and Canada. Table F-3 shows that steam generation capacity generally ranges from 2 to 4 lbs of steam per lb of refuse (or from 4,000 to 8,000 lb of steam per ton of refuse). The average value for convective systems runs approximately 2.5 lb of steam per lb of refuse, whereas the average for waterwall systems is about 3.6 lb of steam per lb of refuse. It should be noted, however, that these are *design* steaming rates. It is anticipated that somewhat lower performance will be obtained in practice (10-30% lower). At Norfolk, for example, the actual excess air levels range between 80% and 100%. As described above, this results in a 10-15% reduction in steam-generating rate.

As seen from Table F-3, the available information on steam credits is very limited. The price for steam is very sensitive to such local conditions as:

- Steam quantity.
- Necessity for reliability.
- The fraction of total steam demand supplied by the incinerator.
- The type of buyer.

The credits listed vary from $0.20 to $0.60 per 1,000 lb of steam.

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   PHS, *BSWM*, (Preliminary).

TABLE F–3

INCINERATORS WITH MAJOR HEAT RECOVERY

Location	Type of Installation	Design Refuse Capacity TPD	Refuse Higher Heating Value (Btu/lb)	Type of Heat Recovery System	Consumer
Atlanta, Georgia	Volund	700	3900^b	Two-drum bent tube boiler located in each of four furnace flues	Sold to local steam heatin
Chicago, Illinois (Southwest)	Refractory	1200	–	4-convection boilers	–
Miami, Florida	Refractory	900	–	4-convection boilers	Sold to a hospital
Hempstead, L.I., N.Y (Oceanside)	Refractory	600	4500^b	2-convection boilers	2500 kw internal power and water desalination
U.S. Naval Station Norfolk, Virginia	Waterwall	360	4700^c 3840^c	2-waterwall systems	Used in conjunction with stream line to supply stea docked ships
Braintree^a	Waterwall	240	5000^b	2-waterwall systems	–
Providence, R.I.	Refractory	–	–	4-convection boilers	–
Oyster Bay, N.Y	Refractory	–	–	4-convection boilers	Internal heating and elect generation
Boston, Massachusetts	Refractory	–	–	3-convection boilers	Partially used for internal steam supply to nearby h has been discontinued
Hempstead, L.I., N.Y (Merrick)	Refractory	700	4500^b	2-convection boilers	–
Chicago, Illinois^a (Northwest)	Waterwall	1600	5000^b	4-waterwall systems	–
Hamilton, Ontario	Waterwall	600	5000^b	2-waterwall systems	–
Montreal, Quebec^a	Waterwall	1200	5000^b	4-waterwall systems	–
Rotterdam	Waterwall	1540	2650^c	4-waterwall systems	Power station
Munich (Nord)	Waterwall	1300	2210^c	2-waterwall systems	Power station
Paris (Issy)	Waterwall	1800	3450^c	4-waterwall systems	Power station
Amsterdam	Waterwall	2000	3600^b	4-waterwall systems	Power station
Dusseldorf	Waterwall	1000	2600^b	4-waterwall systems	–
Mannheim	Waterwall	1000	2700^b	2-waterwall systems	

Notes:

a. Under Construction

b. Design Value

c. Measured Value

Source: References 2, 3, and 9

A

OPERATIONS

	Steam Pressure psig	Steam Generation Rate Steam/ Refuse	 Steam/10 Btu	Steam Generating Efficiency	Steam Credit $/1000	Design % Excess Air
g system	175	1.62^b	415^b	42.0^b	0.20	–
	–	2.0^b	–		0.625	–
	250	0.330^b	–	–	0.70	–
eneration	460	2.75^b	610^b	61.0^b	–	150
main	267^c	3.35^c	700^c	72.2^c	–	50
m to	280^c	2.77^c	722^c	71.2^c	–	–
	–	3.0^b	600^b	–	–	50
	–	–	–	–	–	–
ric power	–	–	–	–	–	–
heating – ospital	–	–	–	–	–	–
	–	2.0^b	445^b	–	–	200
	250	3.3^b	660^b	67.0^b	–	80
	–	4.2^b	–	–	–	50
	–	4.0^b	–	–	–	–
	400	1.69^c	645^c	72.5^c	–	–
	2,920	1.58^c	715^c	71.5^c	–	–
	925	2.10^c	615^c	72.0^c	–	–
	611	2.15^b	595^b	69.0^b	–	–
	1,422	1.6^b	615^b	69.0^b	–	–
	1,720	1.9^b	700^b	69.0^b	–	–

B

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APPENDIX G

REFUSE COMPOSITION AND PROJECTION DATA

APPENDIX G

REFUSE COMPOSITION AND PROJECTION DATA

A. ADDITIONAL REFUSE COMPOSITIONS

Table G-1 shows municipal refuse composition data for four locations in the United States. The late date at which this information was received prohibited its incorporation into Table IV-2 of Section IV which was utilized to develop an estimate for the national annual average refuse composition.

The last row in Table G-1 shows, for the four sets of data presented, the averages of each refuse category on a yard-waste-free and miscellaneous-free basis. Comparison of these averages with the values developed in Table IV-3 in Chapter IV shows excellent agreement. This agreement is further indication that the calculated average composition presented in Table IV-3 is a credible estimate of the national annual average composition of municipal refuse on this reduced basis.

B. REFUSE CATEGORY PROJECTION DATA

The growth rates presented in Table IV-12 of Chapter IV for each refuse category were obtained from the curves in Figures G-1 through G-9,* which show the relative growth rates of selected indicators of waste generation chosen to represent the nine refuse categories (excluding miscellaneous) normalized to the base year 1968. Each indicator was developed to represent the overall growth rate of all components making up a particular category of municipal refuse. For example, the indicator for plastics, shown in Figure G-1, was developed from weighted averages of U. S. domestic consumption projections for plastics in: packaging, housewares, furniture, toys, and synthetic non-woven textiles. These are major components of the plastics category of municipal wastes; and, therefore, projection of the consumption of these commodities should provide a realistic estimation of the growth rate of plastics in municipal refuse. Projections for paper, because it is such a critical component of refuse, were based on the total U. S. consumption of paper, including paper imports and accounting for recycle.

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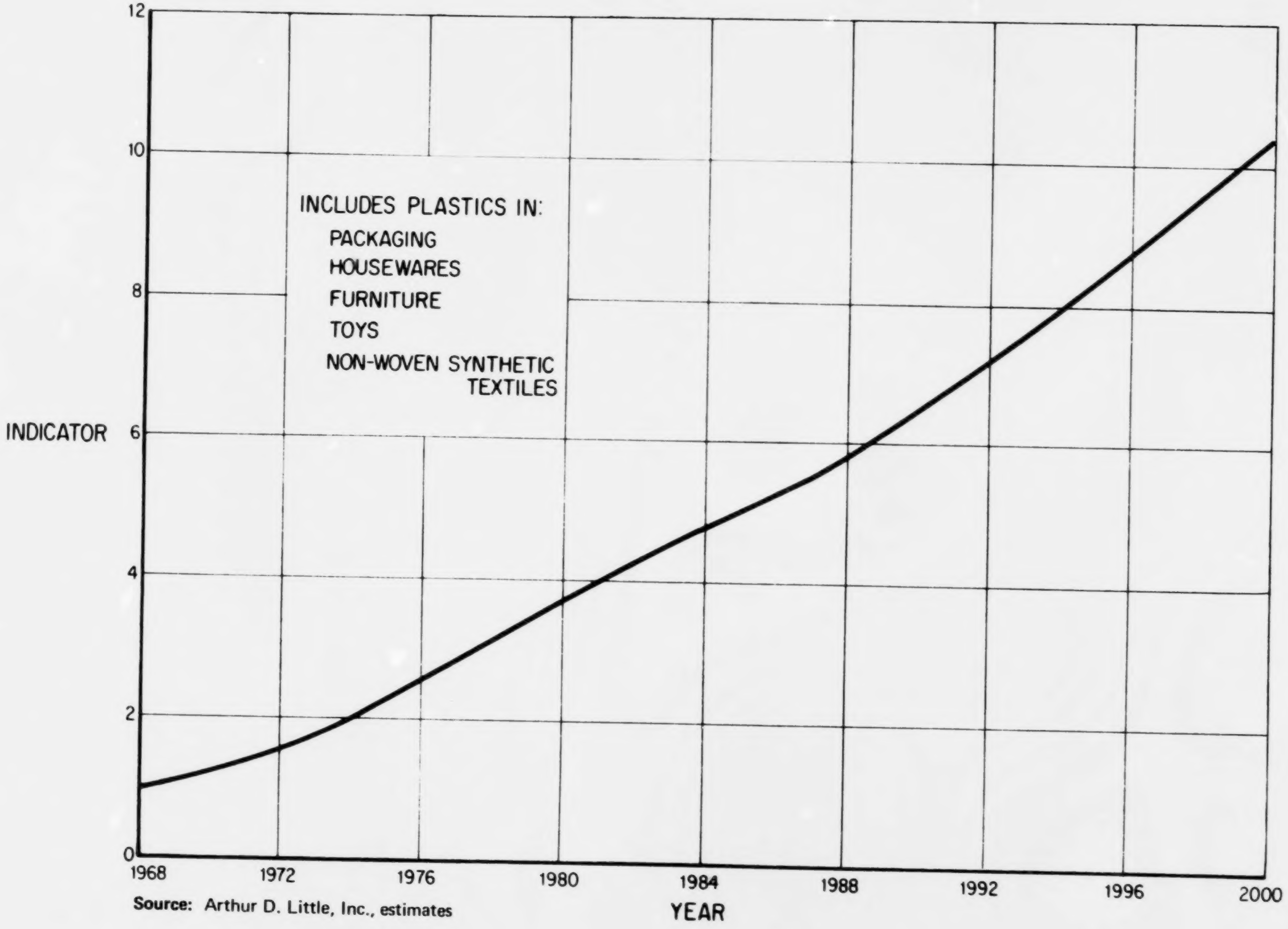
*References indicated on these figures are listed in Section C.

TABLE G-1

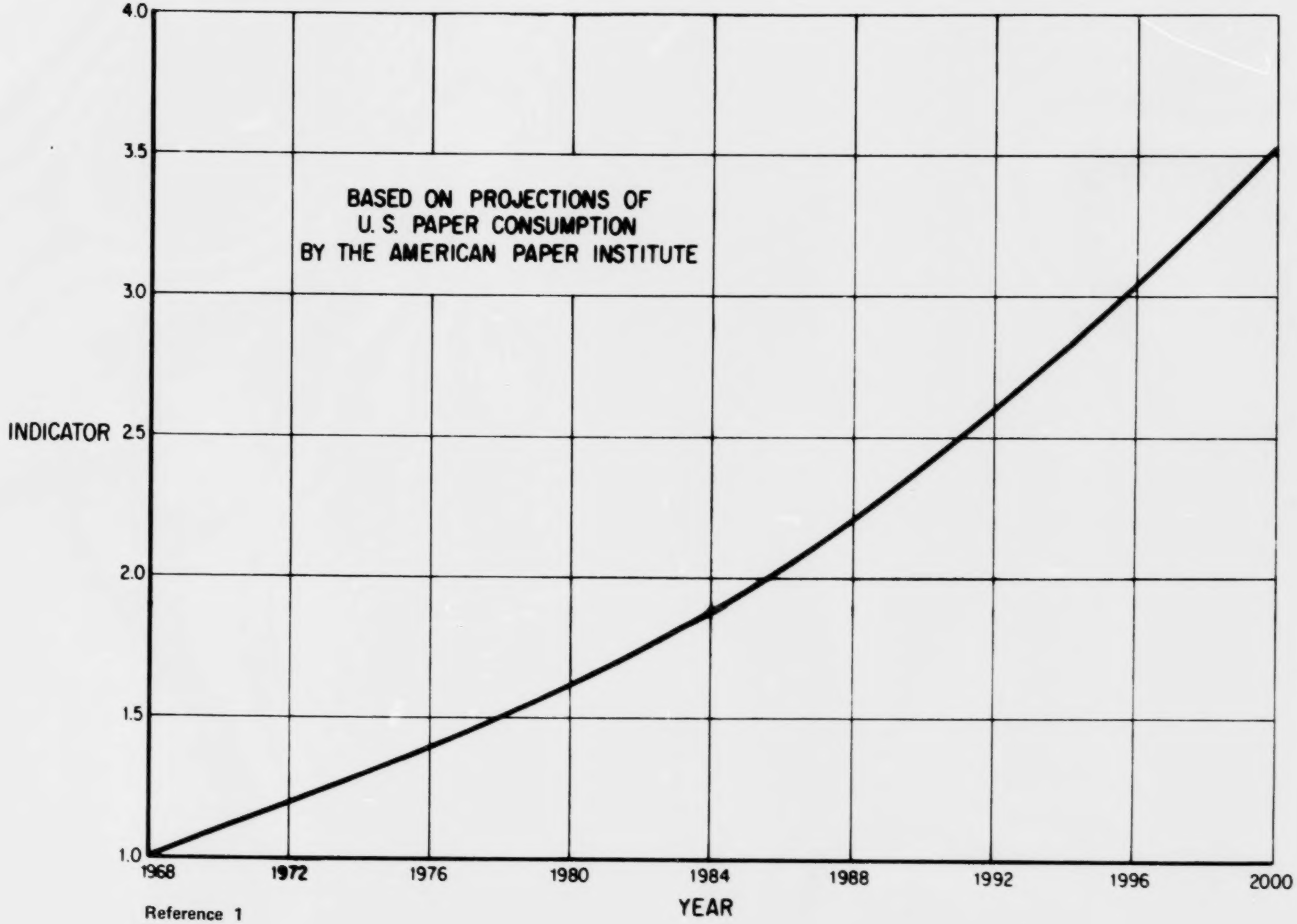
ADDITIONAL SOLID WASTE COMPOSITION DATA
(as-fired basis)
Weight %

Location	Waste Source	Glass	Metal	Paper	Plastics	Leather & Rubber	Textiles	Wood	Food Wastes	Yard Wastes	Misc.	Total
Southeastern Community #1	Residential	10.5	6.8	30.2	---- 3.1 ----		5.2	1.7	20.3	11.1	11.1	100.0
Southeastern Community #2	Residential	9.5	8.1	44.9	---- 3.5 ----		3.2	3.1	11.0	9.8	6.9	100.0
Southeastern Community #3	Residential	6.5	8.8	53.2	---- 2.6 ----		2.0	3.2	17.5	2.8	3.4	100.0
Southeastern Community #4	Residential, Commercial & Industrial	10.3	8.6	58.7	---- 3.0 ----		1.8	0.4	12.2	1.6	3.4	100.0
Average		9.2	8.1	46.7	---- 3.1 ----		3.1	2.1	15.2	6.3	6.2	100.0
Average (on a yard waste-free and miscellaneous-free basis)		10.6	9.2	53.4	3.5		3.5	2.4	17.4	–	–	100.0



Source: Arthur D. Little, Inc., estimates

FIGURE G-1 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. PLASTICS PRODUCTION (1968=1)



Reference 1

FIGURE G-2 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. PAPER PRODUCTION (1968=1)

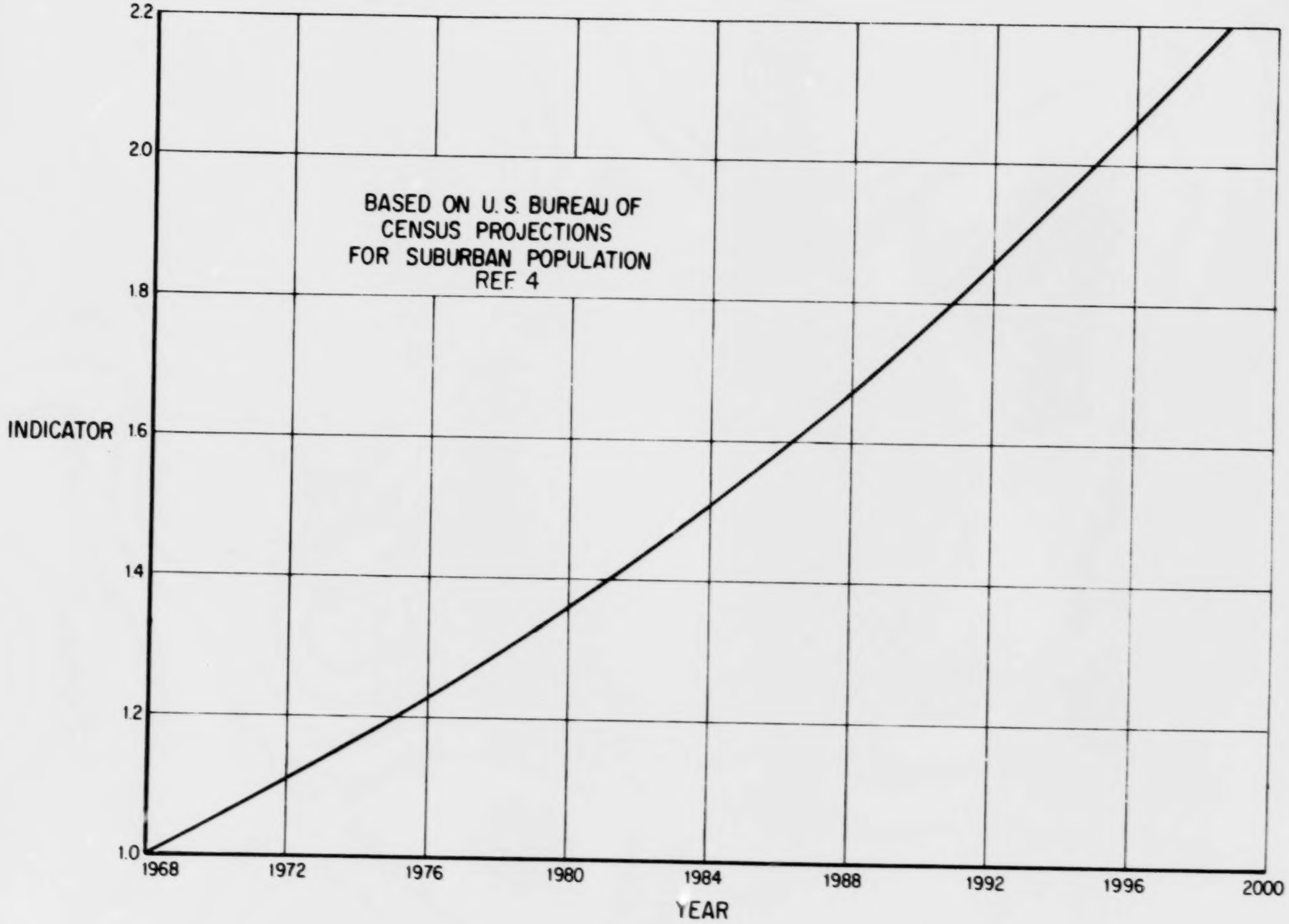
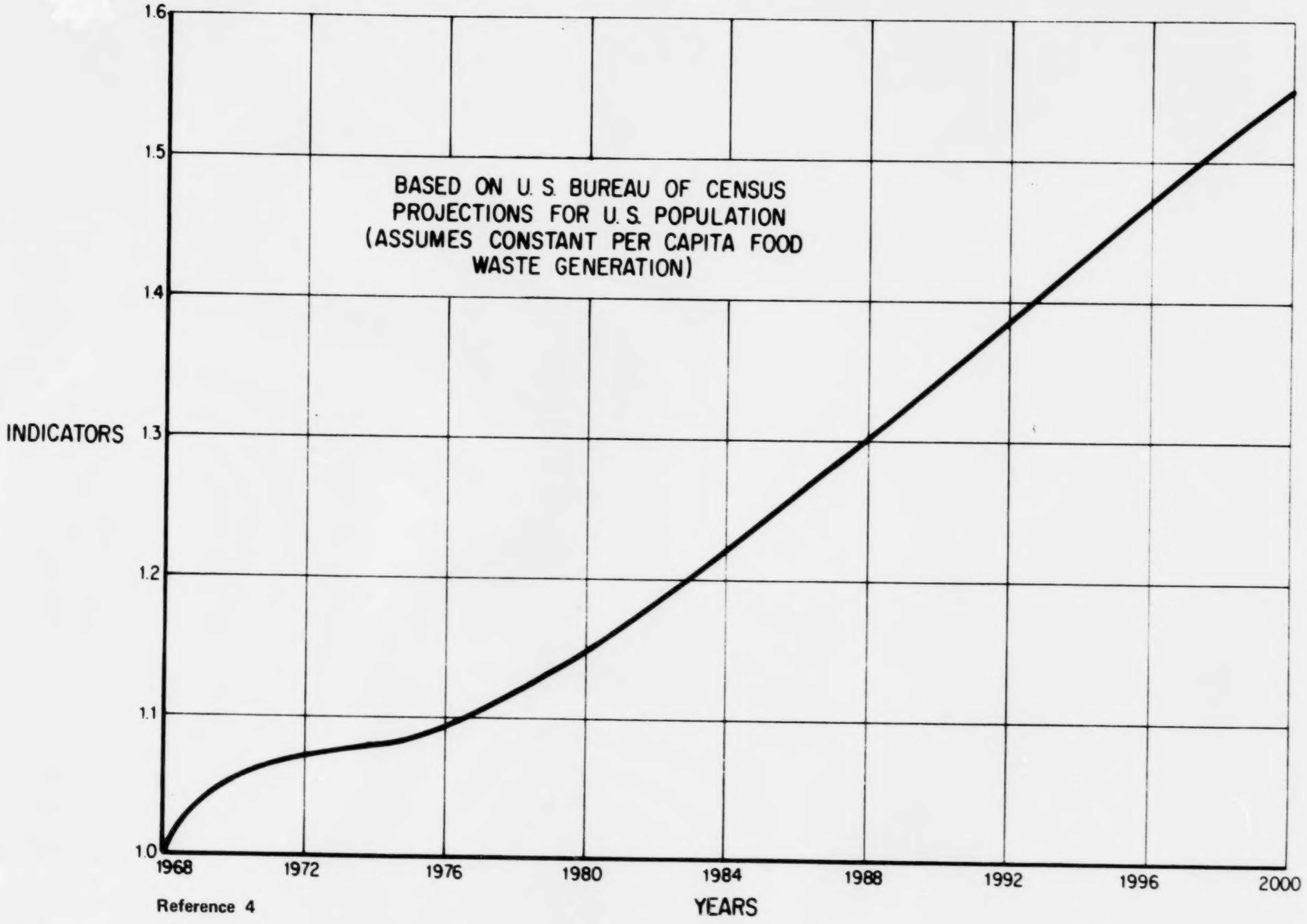
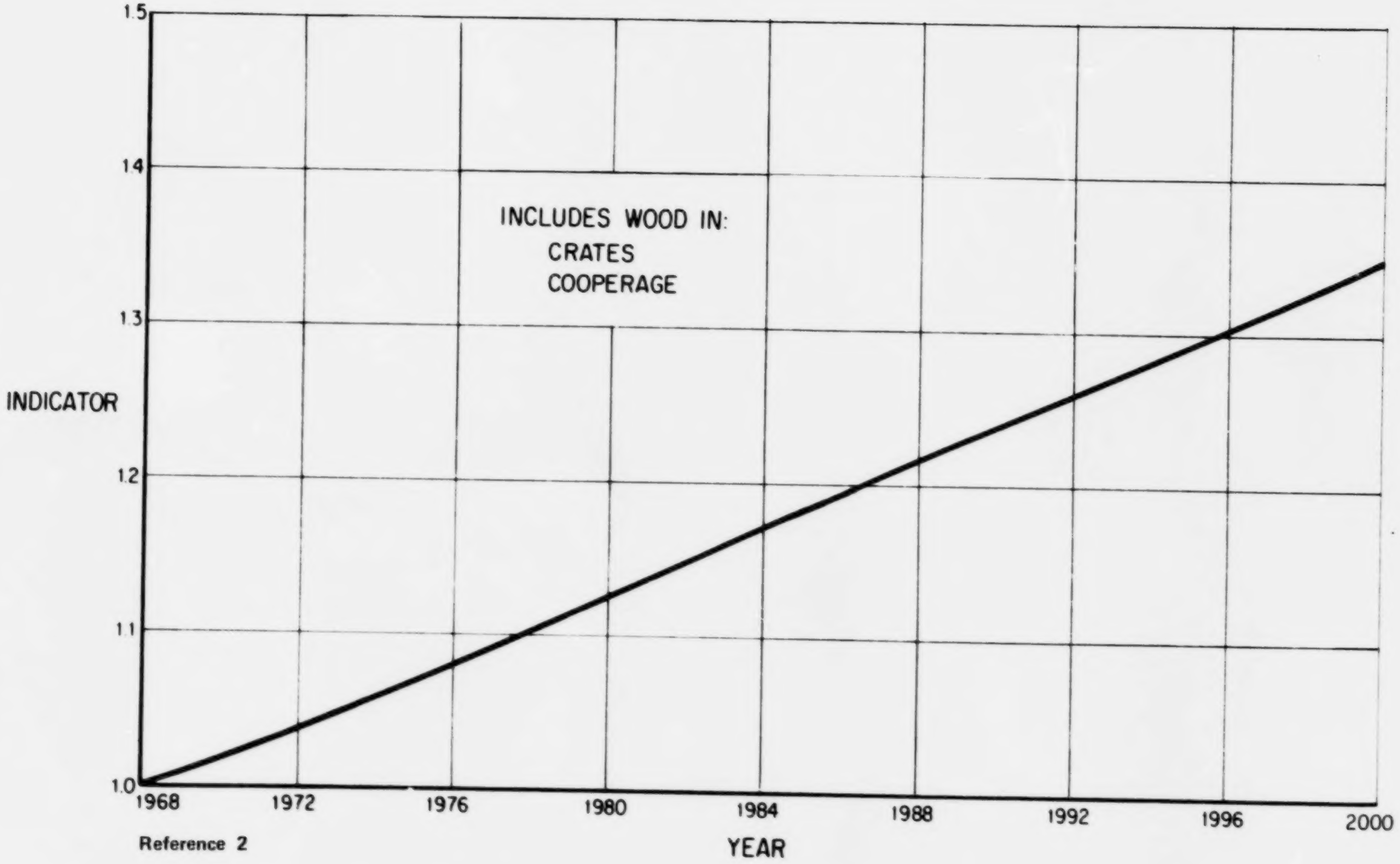


FIGURE G–3 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. YARD WASTES GENERATION (1968=1)



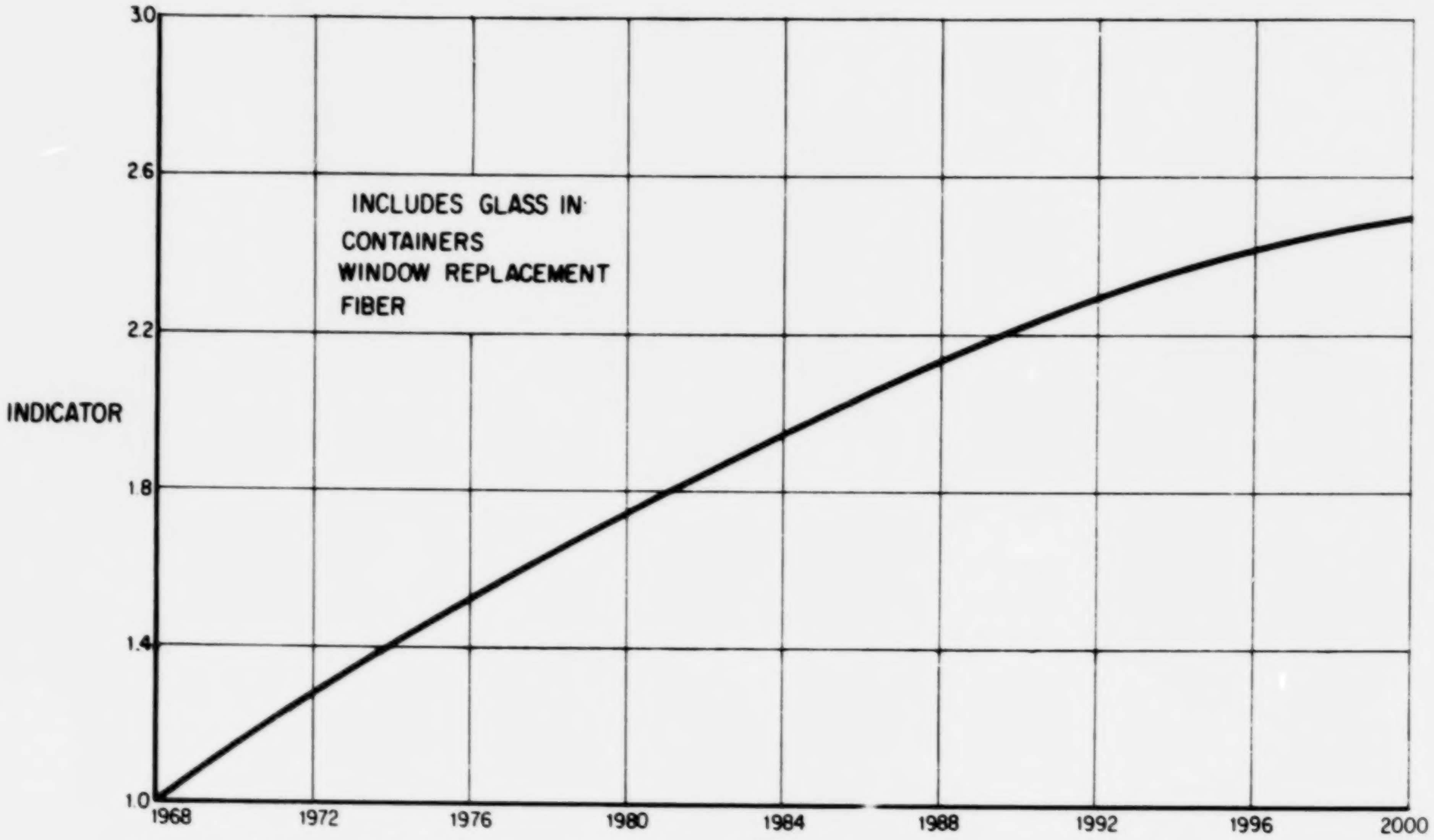
Reference 4

FIGURE G-4 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. FOOD WASTES GENERATION (1968=1)



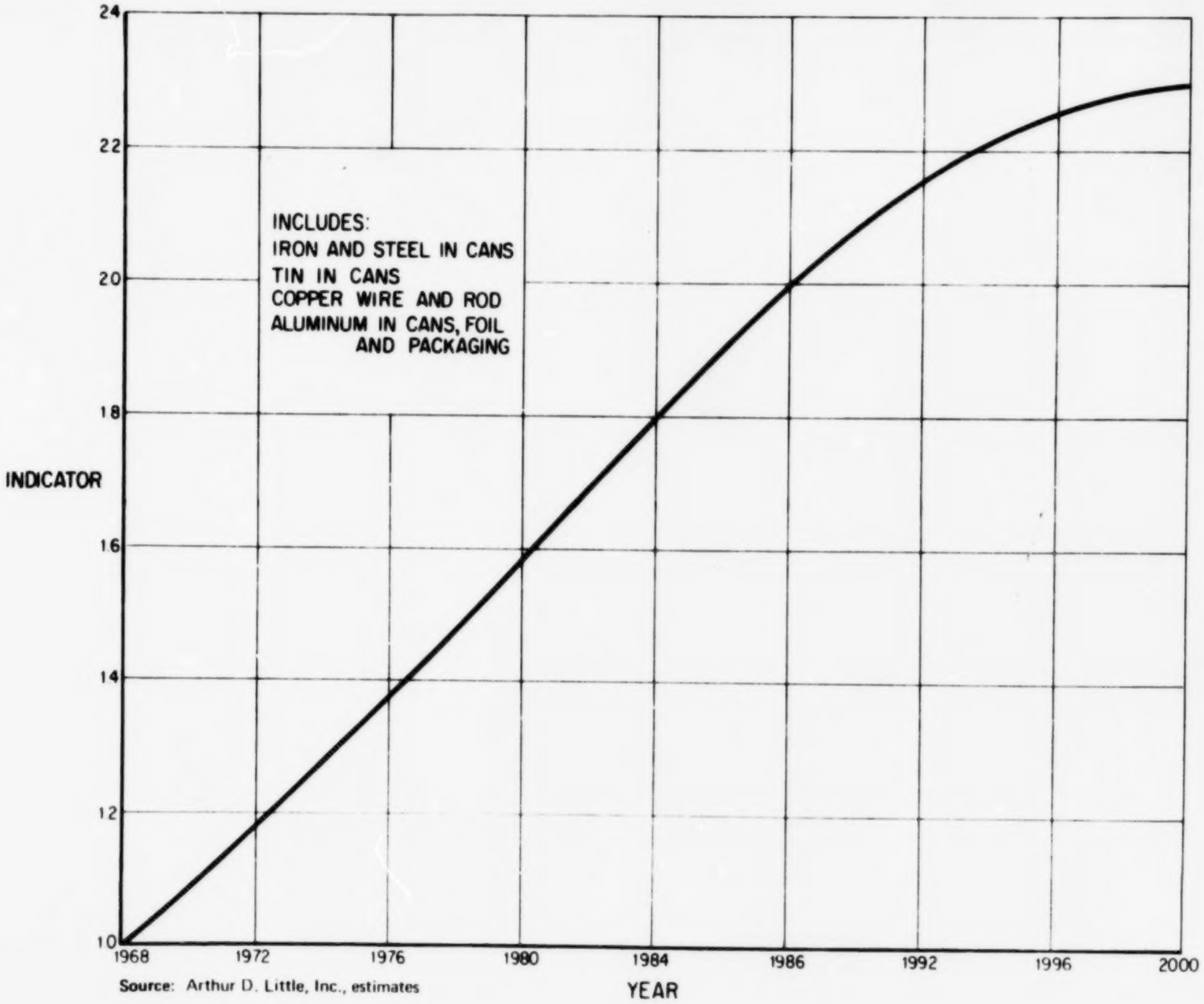
Reference 2

FIGURE G-5 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. WOOD GENERATION (1968=1)



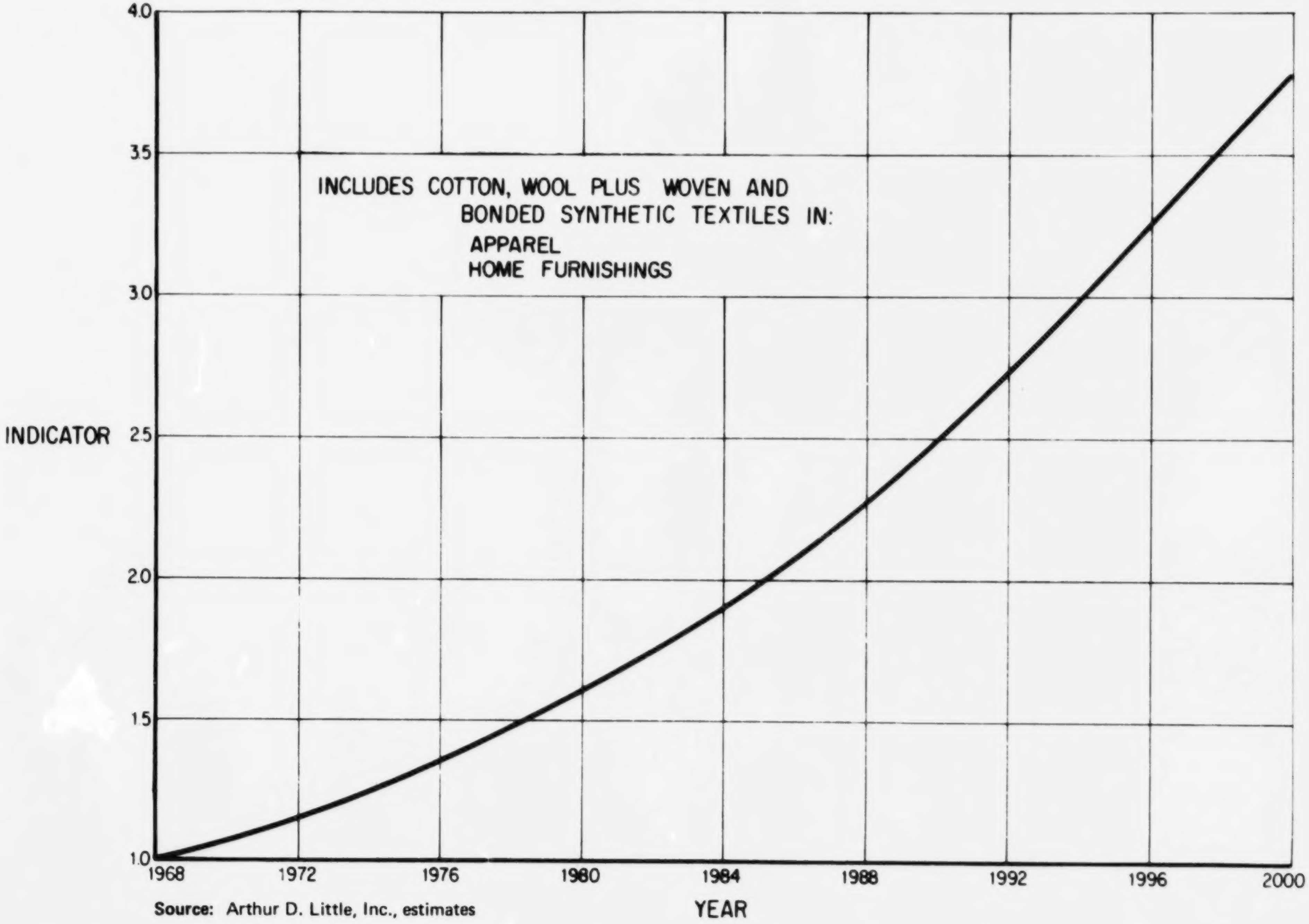
Source: Arthur D. Little, Inc., estimates

FIGURE G-6 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. GLASS PRODUCTION (1968=1)



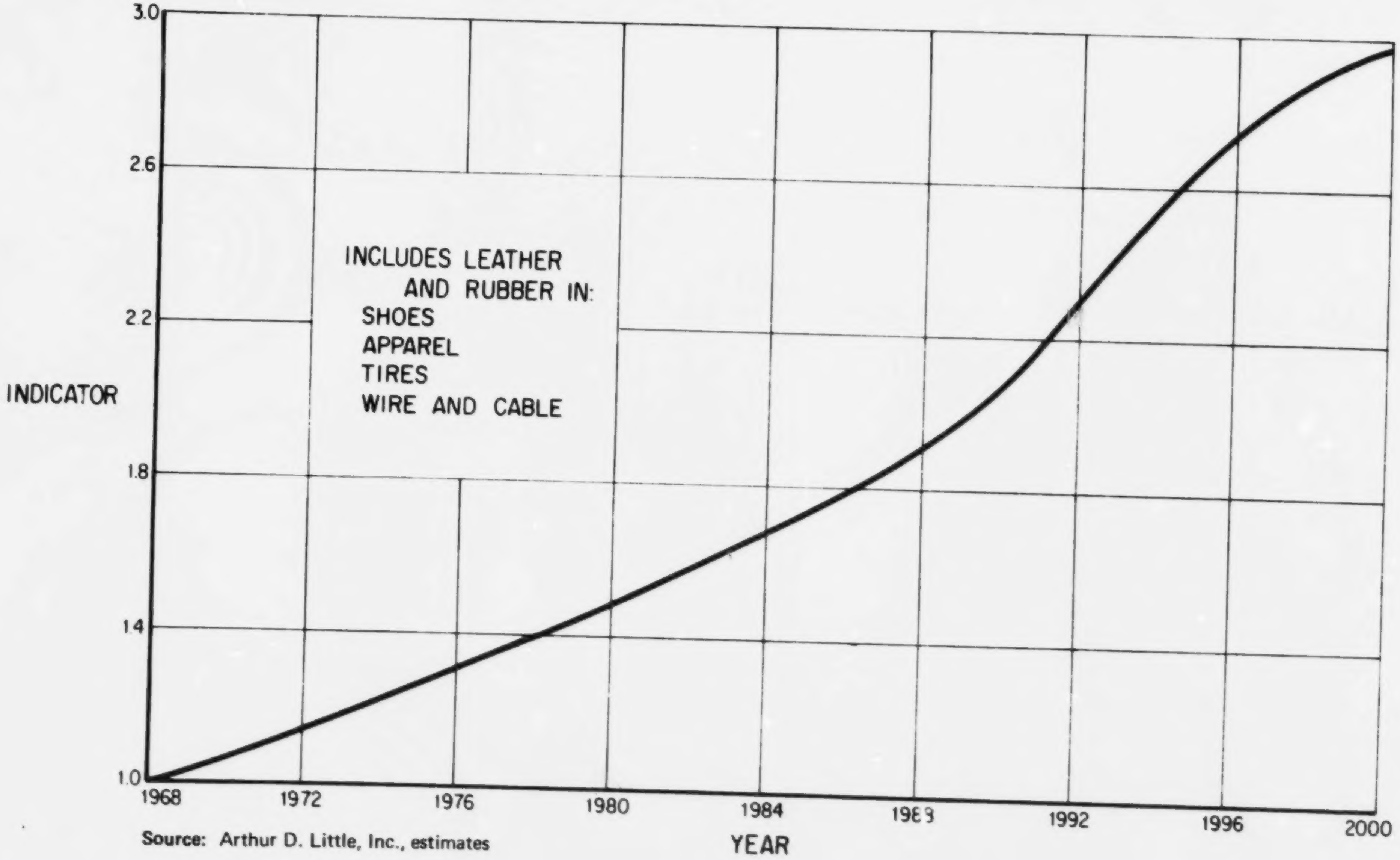
Source: Arthur D. Little, Inc., estimates

FIGURE G-7 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. METAL PRODUCTION (1968=1)



Source: Arthur D. Little, Inc., estimates

FIGURE G-8 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. TEXTILE PRODUCTION (1968=1)



Source: Arthur D. Little, Inc., estimates

FIGURE G-9 THE RELATIVE GROWTH RATE OF INDICATORS OF U.S. LEATHER AND RUBBER PRODUCTION (1968=1)

It should be noted that there are varying lag times between the purchase (consumption) of these components and their subsequent disposal. These lag times have been estimated and incorporated into the development of the indicators for categories which are changing rapidly. Plastics packaging, for example, ordinarily has no lag time associated with its disposal. Plastics in furniture, however, may have lag times varying from a few years to thirty years or longer, depending on the type of furniture and its use. An average lag time of ten years was used for plastics in furniture.

For the refuse categories not directly related to the production and consumption of commodity items, such as yard waste and food wastes, other indicators were selected. For example, the growth rate of the United States suburban population was utilized as an indicator for yard waste growth (Figure G-3). These suburban projections were based on U.S. Department of Census statistics.* In developing Figure G-4 for U.S. food waste generation, it was assumed that, in general, the per-capita consumption of food would remain relatively constant, and, therefore, the generation of food wastes would be directly related to the increase in United States population, as forecast by the U.S. Census Bureau.*

It should be again noted that the indicators as developed in Figure G-1 through G-9 are not in themselves national projections of the quantities of the various categories contained in national refuse. Each indicator merely projects the national growth rates of materials, goods, or other pertinent indices chosen to reflect the overall growth of that particular refuse category with appropriate adjustments, when applicable, for lag time between consumption and disposal.

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APPENDIX H

THE INCINERATION PROCESS

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APPENDIX H

THE INCINERATION PROCESS

A. INTRODUCTION

This appendix summarizes the equipment options, general combustion principles, and criteria of performance applicable to contemporary incineration practice. A comprehensive discussion of these topics is beyond the scope of this report. They are included in summary form, however, for the benefit of readers unfamiliar with the details of incinerator practice and principles. Also, by consolidating the material to facilitate referencing, we can minimize the need for repetition of these topics in the body of the report.

To those familiar with contemporary incineration equipment, Section B (The Municipal Incinerator) will be unnecessary reading. To a large extent, however, the body of the report presumes an understanding of the major processing steps, equipment types and functions, and equipment equivalents presented there.

Section C (Principles of the Incineration Process) is a brief discussion of existing combustion theory and practice which is applicable to the incineration process. In general, it is a description of the heat, energy, and mass transfer or transformation processes common to most combustion systems. The presentation is not intended as a detailed summary of combustion theory, fluid mechanics, heat transfer, etc. Rather, it illustrates some of the properties of refuse in comparison to other fuels and describes the basic grate processes and the chemical and physical processes characteristic of the overfire volume. Where desirable to avoid duplication, the reader is referred to other portions of this report.

Section D (Criteria of Incinerator Performance) presents a brief discussion of the five fundamental criteria of incinerator performance. Although this report is specifically directed at the air pollution aspects of incineration, it is recognized that incinerators exist primarily as a means for the disposal of solid wastes (through volume reduction and residue sterilization). Minimum air pollution, an increasingly important aspect of process design, can be conveniently viewed as one of several performance criteria for any solid waste disposal system. These criteria provide a context for the evaluation of the air pollution aspects of existing plants, alternatives in new plants, advanced incineration concepts, and air pollution control equipment.

B. THE MUNICIPAL INCINERATOR

The objective of this portion of the report is to answer the question: What is an incinerator? The question is not easy to answer. Unlike the chemical or manufacturing industries, the incineration business employs a wide variety of designs to do the same job. Rarely are two U.S. plants built to precisely the same design. This individuality reflects both the growth of incineration technology in recent years and the large number of basic design parameters which are so poorly understood that they bend readily to the personal prejudices of the design engineer.

Thus, an incinerator can be many things. The paragraphs which follow outline very briefly the options in incinerator design. Any one of the pages or even paragraphs would require expansion to a chapter or report in its own right if the subject were dealt with at a level of detail fully supporting a decision-making process. It is hoped, however, that after reading this section of the report the reader will have familiarity with many of the terms involved in describing an incinerator and with the wide variability which is possible between systems.

1. Collection and Delivery of Refuse

In the incinerator system, the handling of refuse begins with the delivery of materials to the site. While in the United States most refuse is delivered to the site in motor vehicles, other countries sometimes use railroads or water transportation. Delivery vehicles include open dump trucks, commercial vehicles, private cars, and, most importantly, trucks with equipment for compression and densification of the bulky refuse. In some instances, huge compaction truck trailers are employed to ferry refuse from centrally located transfer stations to a distant incinerator site. Such transfer stations are serviced by the smaller collection vehicles described above.

The refuse loaded into the original collection vehicles usually has a density of about 5-15 lb/cu ft depending on the nature of the refuse and how it has been packed at the refuse generation point. Refuse can be loosely placed in collection receptacles, manually stamp packed, or, more recently, compacted at the site by compression and/or baling devices, sometimes after being ground or shredded. A power compaction unit can compress the refuse at the generation site (such as at commercial establishments, hospitals, apartments, hotels, etc.) to a density of about 30-60 lb/cu ft. However, most refuse loaded into vehicles at the collection site is compacted in the truck body to 15-30 lb/cu ft by means of mechanical and/or hydraulic systems employing vehicle motor power. The latter compaction is employed in most municipal and private collection vehicles to increase the payload capacity of the vehicle.

Compaction or densification of refuse is also desirable for transport in railroad cars or in waterborne barges. While bulk materials are handled in both of these modes of transportation, there are advantages in compaction to bales or blocks. Indeed, baled compressed refuse can constitute an almost optimum load for rail cars or barges. Compacted refuse can also be containerized for rail or barge transportation. Refuse that is left in bulk form can be carried in railroad cars with side openings or in regular cars that are tipped for dumping just as they are for unloading coal or grain. The unloading of bulk refuse from barges is more of a problem; the kind of equipment used to unload bulk coal and iron ore is not suited to refuse. What is required is a crane with a clamshell or orange peel bucket. A similar crane operation, but with other devices for holding the refuse, may be used in the future for unloading barges loaded with containers or bales of refuse.

2. Refuse Handling and Storage

Once the refuse arrives at the incinerator site, it must be handled for storage and for feeding into the next stage in the system. Refuse is most often received and stored in a pit below ground level. A traveling crane with a bucket is used to pile the refuse for storage and to move it away from the unloading area so that the pit can accommodate additional refuse. At the same time, the crane and bucket can be used to feed the incinerator furnace.

Three types of buckets are in common use for handling municipal refuse: the clamshell bucket, the grapple bucket, and the orange peel bucket. The clamshell and grapple buckets can be equipped with teeth to assist in digging into the refuse for a full bucket. The orange peel bucket does not require teeth to grab the refuse, even for unusual or large pieces. However, with the orange peel, it is difficult to clean the floor of the receiving pit, while the clamshell and the grapple are well suited to cleaning the pit providing the teeth are removed. A steel plate is sometimes used to cover the teeth when cleaning the floor of the pit. Pit cleaning is important for sanitation, good housekeeping, and elimination of odors from decomposing refuse.

In some cases, a paved floor is used instead of a receiving pit; the refuse is deposited on the floor by the collection vehicles. The refuse can then be pushed onto a wide conveyor for loading either into the feed hopper of the incinerator furnace or to shredding or compacting devices. Alternatively, a front-end loader or dozer blade can be used to push the refuse through an opening in the floor to feed the incinerator furnace.

While open receiving areas are possible, they are infrequently used. The receiving area should preferably be closed to protect the refuse from blowing in the wind and causing a nuisance, to control dust and odors, and to prevent snow and ice from interfering with the movement of vehicles. Closure of the refuse receiving area also assists in refuse moisture control by keeping rain off and also preventing excessive drying. Moisture stability is helpful in obtaining uniform combustion temperatures in the furnaces.

Most incinerators do not have a scale to weigh the incoming refuse. However, for plant performance evaluation and for toll disposal, it may be necessary to know the weight of the refuse. Various types of scale are available. Some are manually operated with the weights recorded by the scale operator. Others can furnish a printout of the gross, tare, and net weights, together with the license or code number of the vehicle as supplied by the weighmaster. Newer installations are using a recently developed scale for automatic weighing; the driver of the incoming vehicle inserts a coded card to supply the vehicle code number and the tare weight of the vehicle, and the automatic system prints the gross weight and net weight, as well as the date and time of the delivery.

3. Size Control and Salvage

In the past, oversize or otherwise undesirable refuse has been controlled by exclusion at the tipping location or by selective removal from the pit by the crane operator. Under supervision, bulky articles can be deposited in a specific area of the pit or they can be carried directly to the residue disposal site without passing through the incinerator furnace. The latter method is often used for bulky metal items such as refrigerators, stoves, large metal parts, which contain little or no combustible material. If the item contains biodegradable material it is cleaned before it is taken to the residue disposal site. Combustible oversize items are preferably broken up and incinerated.

Most refuse can be reduced in size by shearing or shredding. Shearing is a controlled method for reducing all refuse to a given maximum size (for example, 3 feet, 2 feet, or 1 foot) by passing it through a shear or series of shears, or through a single or multiple guillotine. Shredding, which is rapidly coming into increased use can be done with any of three types of device: horizontal shaft hammermills, vertical shaft hammermills, and horizontal shaft rotating shears. The rotating shear has found only occasional use in special installations, most of which are experimental. At present most installations use hammermill-type devices for shredding of refuse, usually employing horizontal shaft and relatively high-speed hammermills. However, there may be a shift toward the use of lower-tip-speed mills and vertical shaft mills. Lower tip speeds reportedly decrease wear on the hammer or shredder components. Further, there is a claimed advantage in the use of a vertical shaft shredder in which the size of the refuse steadily decreases as the material passes downward around a cylindrical rotor operating within a conical housing. The size reduction of the refuse can be controlled at the amount desired so that there is no waste of power from overshredding or excessive size reduction, as often occurs with the horizontal shaft hammermill. In addition, the vertical shaft shredder uses the clearances between the rotor and the housing for size control and does not need grate bars under the rotor as does a horizontal shaft shredder.

While the shredding of refuse may permit some compaction and thus better utilization of landfill sites for disposal of refuse, its most important purpose is coming to be the preparation of a suitable feed for recent and more sophisticated incinerators using suspension burning. For this purpose, the refuse is shredded or reduced in size to mostly less than 1 inch and with no particles larger than 2 inches. The refuse, thus shredded, is then blown into the furnace for incineration with combustion largely while in suspension, followed by residual burning on a grate or other type of hearth. Suspension burning of shredded refuse can also be used with special ash melting furnaces employing the design principles used in metallurgical vertical shaft or cyclone-type furnaces.

In many newer incinerator systems, noncombustible items can be processed in the furnace to remove paint or other coatings and to provide a cleaner metal residue. In some cases, residue metallics can be separated with screens, with magnetic devices or both, and the clean metal salvaged as metal scrap.

Although there has always been some effort to salvage reusable materials, particularly in Europe, such efforts are receiving new emphasis in the United States at the present time. In the past, salvage operations have been largely manual, with minor assistance from mechanical equipment. The principal salvage point has been a conveyor, which carries the refuse past workers who remove selected pieces of refuse and deposit the different varieties in separate chutes or containers. Thus, papers would go into one receptacle, cloth into another receptacle, glass into a third, metals into a fourth, copperwire into a fifth, and so forth.

In recent years, there has been a definite trend toward the use of mechanical devices for separation and salvage of various materials from refuse. Machine separation has been necessary to the successful operation of most composting plants. In some cases, these plants have been changed from compost to salvage operations in order to avoid shutdown due to technical or economic limitations on the operation of the compost plant. Mechanical separation methods include the use of pneumatic devices, ballistic separators, size and rolling separators, and magnetic and static separators. Some of the shredders and grinders now available for processing refuse are capable of making certain size and weight selections during shredding operations. As an illustration of current research in the art of mechanical separation, an automatic system is under development to separate clear glass granules from colored glass granules, so that the clear glass granules can be reused in the production of new glass. This is particularly important with the increased use of one-way glass containers. Such recycle of glass is being encouraged by the Glass Container Manufacturers Institute and could be an important step toward conservation of raw materials.

4. Incinerator Feed Systems

The incinerator furnace provides the environment for controlled combustion of solid wastes with air. The furnace usually includes grates to support the burning material within a refractory or other enclosure. The refuse is processed by controlled oxidation with liberation of heat, producing flue or combustion gases and a residue or ash. The refuse to be processed in the furnace must be fed at controlled rates with suitable material handling equipment. The ash residue must be removed and transported in bulk to a disposal area, while the effluent flue gases must be removed and delivered to the stack or chimney after suitable treatment for control of air pollution.

The feeding of the refuse may be either batch or continuous, although the recent trend has been toward the use of continuous firing to improve process control. Batch feeding of refuse directly into the furnace is done, in most cases, with a clamshell bucket or grapple attached to a traveling crane; the rate of feed is controlled by the time cycle and the degree of bucket loading. In a few plants, a front-end loader operating on a paved floor charges the furnace.

A ram-type feeding device (Figure H-1)* is sometimes used for controlled feeding. With such a system, either the ram can clear the hopper at each stroke or an oversize hopper can be filled with refuse and the ram used to shear a horizontal section of refuse at selected intervals. The ram feeder provides an air seal at the feed to the furnace, an improvement over the bucket or the front-end loader systems of batch feeding, which usually let in undesirable quantities of cold air, as well as releasing occasional puffs of flames or hot gases, while the charging gate is open. The inrush of cold air can be detrimental to the inside refractory walls of the furnace and can cause smoke evolution by cooling and quenching the burning process. While it is possible to use a two-gate air-lock during batch feeding to keep the air out, such devices are seldom used because of the increased height, cost, and extra maintenance involved in the additional mechanical equipment. However, from a technical standpoint, an air seal should be used.

Newer designs for incinerator systems nearly always specify continuous feeding of refuse to the incineration furnace. Continuous feeding can be accomplished by means of a hopper and a gravity chute; a mechanical feeder, such as a

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*The superscripts in the figure titles and in the text refer to the references listed in Section E.

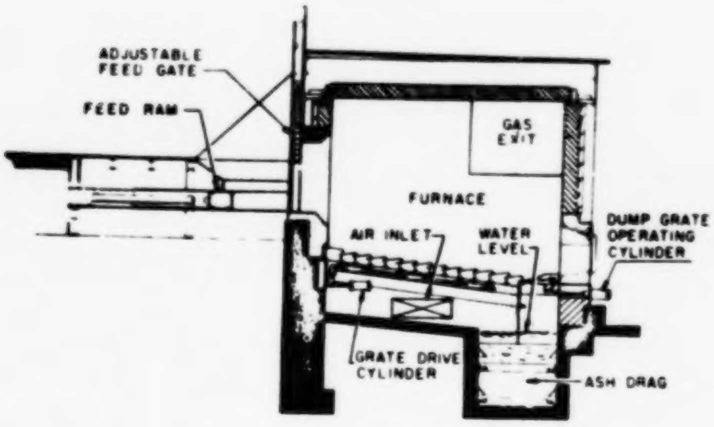
ADJUSTABLE FEED GATE
FEED RAM
GAS EXIT
FURNACE
AIR INLET
WATER LEVEL
DUMP GRATE OPERATING CYLINDER
GRATE DRIVE CYLINDER
ASH DRAG

FIGURE H-1

RECIPROCATING GRATE AND RAM FEED[1]

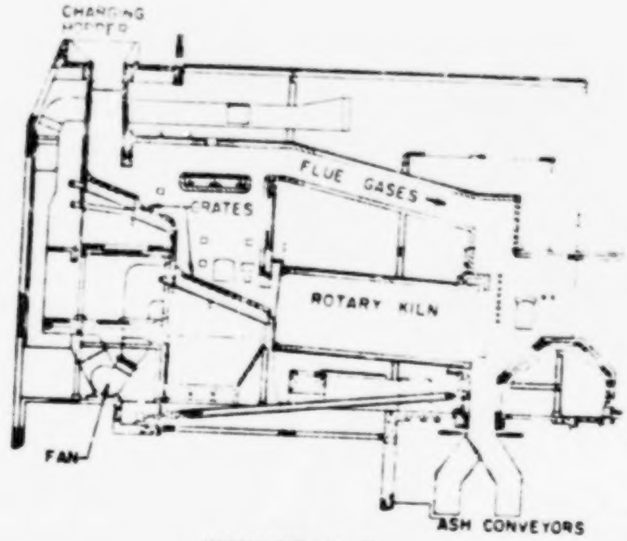
CHARGING HOPPER
FLUE GASES
GRATES
ROTARY KILN
FAN
ASH CONVEYORS

FIGURE H-2

ROTARY KILN INCINERATOR[1]

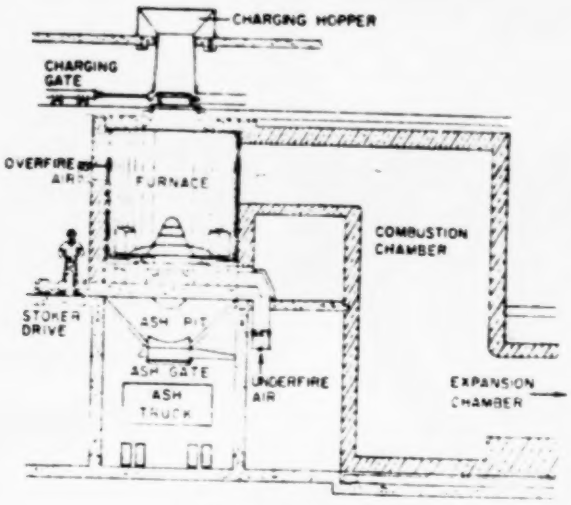
CHARGING HOPPER
CHARGING GATE
OVERFIRE AIR
FURNACE
COMBUSTION CHAMBER
STOKER DRIVE
ASH PIT
ASH GATE
ASH TRUCK
UNDERFIRE AIR
EXPANSION CHAMBER

FIGURE H-3

BATCH FEED CYLINDRICAL INCINERATOR[1]

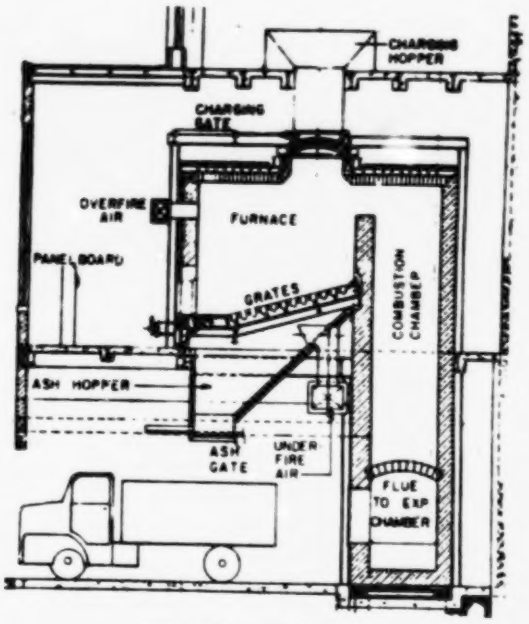
CHARGING HOPPER
CHARGING GATE
OVERFIRE AIR
FURNACE
PANELBOARD
GRATES
COMBUSTION CHAMBER
ASH HOPPER
ASH GATE
UNDER FIRE AIR
FLUE TO EXP CHAMBER

FIGURE H-4

BATCH FEED RECTANGULAR CELL INCINERATOR

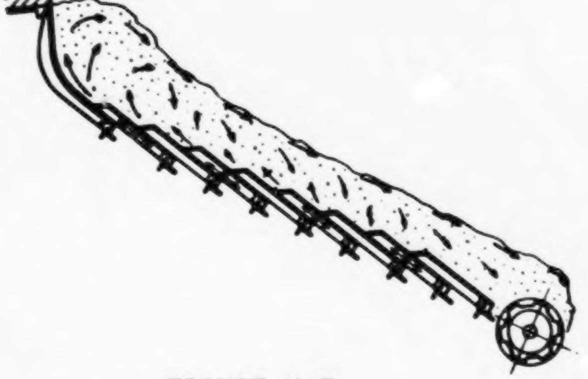

FIGURE H-5

DETAIL OF THE MARTIN REVERSE ACTION GRATE[2]

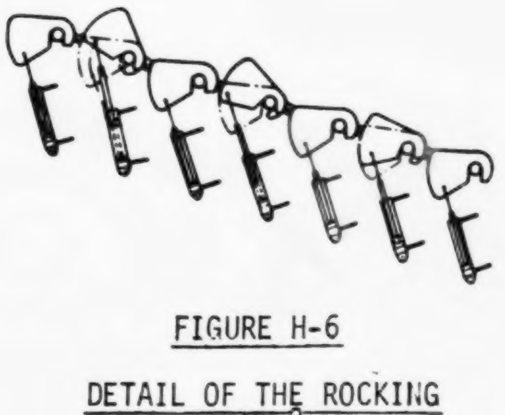

FIGURE H-6

DETAIL OF THE ROCKING GRATE[2]

pusher, ram, rotary feeder, or the like, which can be filled directly from a hopper supplied with refuse by a bucket and crane; a front-end loader from a feeding floor; a conveyor transporting the refuse from the receiving area; or an air injection system (shredding with suspension burning). The most frequently used system is the hopper and gravity chute. A rectangular hopper receives the refuse delivered by the crane and bucket. The bottom of the hopper terminates in a rectangular section chute leading downward to the furnace grate or other feeder conveyor at the entrance to the furnace chamber itself. This gravity chute is either of uniform cross section or flared slightly toward the lower end. It is either refractory lined, made of water-cooled steel plate, or both, to prevent heat damage. Fires in the chute may be caused by faulty chute design (too short or too narrow), by the presence of large or irregular refuse which can provide flues for combustion gases and flame to ascend the chute, or by insufficient material in the chute.

If suspension burning is to be employed in the incinerator furnace, the refuse should be prepared by suitable shredding or grinding, and the most desirable feeding method is air injection. Suspension burning has been used successfully in waterwall boilers for the generation of steam from waste products such as wood bark, bagasse, and similar materials. In conformance with practices in the fossil fuel fired boiler industry, air injection of shredded refuse can be used for corner firing, for spreader firing or for "cyclone" firing, all of which are in commercial use for the generation of steam from powdered or crushed bituminous coal. With suspension burning, a burn-out grate is provided at the bottom of the waterwall furnace chamber to permit completion of combustion of larger particles or slow-burning materials.

5. Grates and Hearths

Nearly all incineration furnaces employ either a refractory hearth to support the burning refuse or a variety of grate types which stoke or mix the refuse during the combustion process in various ways depending upon the type of grate or stoker. Suspension burning is the only process that does not necessarily require a hearth or grate, since most of the refuse is oxidized while in suspension in furnace gases, but even for suspension burning a burn-out grate is often provided at the bottom of the furnace chamber to assure complete burn-out of combustibles in the residue. There are many different types of hearth or grate, each of which has its own special features.

a. Stationary Hearth

Those incinerator furnace systems which operate without grates include the stationary hearth, rotary hearth, and rotary kiln. The stationary hearth is usually a refractory floor to the furnace, which may have openings for the admission of air under slight pressure below the burning material on the hearth, in the manner of the blacksmith's forge. In the absence of underfire air ports, air is admitted along the sides or from the top of the furnace, and combustion proceeds in the same manner as in a bonfire, but with improved conditions due to the re-radiation of heat from the surrounding furnace walls and roof. Unless the refuse being processed provides a porous burning mass, as may be the case with bulky refuse, it is necessary to provide manual stoking with slice bars to stir the mass of refuse in order to achieve a reasonable degree of burn-out.

Stationary hearth furnaces are used for most commercial and smaller industrial incinerators. They are also used in crematories and for hospital wastes, when assisted with auxiliary gas or oil burners to maintain the furnace temperature above 1200-1600°F. The flue gases evolved must be maintained for approximately one to two seconds at or above 1600°F in the presence of adequate quantities of oxygen from air, well-dispersed throughout the gas, to ensure complete oxidation of combustible solids and vapors for the elimination of smoke and odors. This may require auxiliary fuel burners in a secondary combustion chamber.

Increasing numbers of bulky refuse incinerators have a refractory chamber with a refractory floor equipped with a number of air inlet gratings, similar to floor drains. One side, or end, of the chamber is connected to the hot combustion chamber of another incinerator installation. If not, a secondary combustion chamber must be installed prior to the breeching and stack to assure burn-out of combustible gases and particulate. A refractory door permits the opposite side of the combustion chamber to be opened for access. A special extended dozer blade can be used to load the hearth with refuse from a paved platform outside the chamber and to drag out ash residue. Alternatively, it is possible to remove the ash residue by raking with a hoe or by pushing the ash residue beyond the hearth into a depressed area from which the ash can be removed.

b. Rotary Hearth

The rotary hearth, which is seldom used for refuse, involves a rotating refractory table that turns on a vertical shaft by means of a mechanical device operated from below. A stoking device or stationary rabble-arm system is arranged above the rotating table with plows extending downward to move the ash residue toward the periphery of the table during the combustion process and to stir the burning mass to expose the solids to oxygen in the air admitted from above. Air cooling of the rabble-arm support is accomplished by passing the combustion air through the hollow support, through the attached plows, and into the burning mass of material on the hearth.

c. Rotary Kiln

The rotary kiln type of hearth (Figure H-2) has been used for several hundred years in the pyroprocessing industry to move solids in and out of high-temperature combustion zones and to mix them during combustion by rotating them. The metal cylinder is lined with refractory to prevent overheating of the metal, unless special provisions are made for air cooling or water cooling. The kiln is inclined toward the discharge end and the movement of the solids being processed is controlled by the speed of rotation.

There has been little use of the rotary kiln for incinerator furnaces except after the burning of refuse on a multiple-grate system. Since the rotary kiln normally requires all of the air for combustion to enter the unit with the refuse at the feed end, the flow of combustion air is a deterrent to the temperature increase necessary for rapid ignition. The few rotary kilns that have been used for incineration of refuse have been relatively short – perhaps four to five times diameter.

d. Stationary Grates

Stationary grates have been used in incinerator furnaces for a longer time than any grate system except the stationary hearth, which was used in incinerators and crematories prior to the Middle Ages. The original stationary grates were probably metal bars or rails supported in the masonry side walls of the furnace chamber. Subsequently, these bars were replaced with cast metal or fabricated metal grates with provision for rotating the grate sections to permit dumping of the ash residue. While some stoking action can be obtained by shaking the grate, as in partial dumping, stationary grates normally require manual stoking with a slice bar to stir the burning bed of refuse in order to obtain a reasonably complete burn-out of ash residue. Such stationary grates are still in use in many of the older cell-type incinerators. The latter have usually been constructed with a multiplicity of furnace sections or cells, with an opening above each cell for charging.

e. Mechanical Grates: Batch Operations

Mechanically operated grates installed in batch-type furnaces were a natural evolution from the stationary grate furnaces. Although batch-type incineration furnaces have given way to continuous furnaces for new, large installations, many of the new small-capacity incinerators still utilize batch-fed furnaces, either with stationary or intermittently operated grates or without grates, the latter in small commercial and industrial installations.

(1) Cylindrical Furnace Grates. In the circular batch furnace (Figure H-3), the grates form annuli inside the vertical cylindrical walls of the furnace. A solid grate or "dead plate" covers the central area of the annulus. A hollow rotating hub with extended rabble arms rotates slowly above the circular dead plate to provide mechanical stoking or mixing. A center post provides the bearing support of the hub and rabble arms. The rotating hub is covered with a hemispherical "cone" with one or more consecutively smaller "cones" stacked on top of the first one. Forced air (called "cone air") for combustion is supplied through the hub to the hollow rabble arms and thence through openings in the arms to the space just above the dead plate. Additional cone air is supplied to each of the cones, to cool the metal. The annular grate area is divided into pairs of keystone-shaped segments; each pair is arranged to open downward for dumping the ash residue into the ash hopper below. These segmental grates are either hand-operated or hydraulically operated under manual control. It is frequently necessary to poke and slice the ash residue using the access doors around the furnace, in order to clean the fires and to assist in the dumping of the ash residue.

When circular grates are used, the cylindrical furnace is fed intermittently or batch-wise through an opening in the top at the centerline of the furnace. A charging door is used to close the opening between additions of refuse. In the usual method of operation, refuse is placed in the hopper above the charging door or gate preparatory to the next charging cycle. At a signal from the operator, the charging gate is opened, the refuse drops into the bonfire of previously ignited refuse, and the charging gate closes immediately after the hopper is emptied. Additional refuse is charged in repeated cycles at the discretion of the operator until the accumulated ash residue in the furnace requires dumping through the circular grates. The degree of burn-out is at the discretion of the operator; it takes a long time for all combustibles to be consumed, and care must be taken not to stop the burning process too soon.

(2) Rectangular Batch Furnace Grates. Mechanically operated grates in rectangular batch-operated incinerator furnaces (Figure H-4) include reciprocating (pusher) grates, reverse acting reciprocating grates, and rocking grates. The grates are installed in a slightly inclined position from the horizontal, with the lower end of the incline at the ash discharge point. With these grates, the furnace is fed intermittently through an opening in the top and at the higher end of the grate, and the fresh refuse is deposited over the bonfire of previously ignited refuse.

As the burning continues, the grates are operated under manual control to move the burning bed of refuse toward the discharge; with manual control to prevent (ideally) the discharge of residue that has not been completely burned. In some instances, a dump grate is installed at the ash discharge point to hold back ash residue that is still burning, with manual operation of the dump grate after the accumulated ash has been completely burned. At times, it is necessary to manually stoke or slice the fire in order to spread the burning refuse over the grate or remove larger pieces of metal or clinkers that interfere with the desired flow of burning refuse across the grate. Examples of reciprocating or pusher grates include those manufactured by Detroit Stoker Company (Detroit) and Von Roll (Zurich); an example of the reverse acting reciprocating grate is that manufactured by Josef Martin of Munich; the rocking grate is that manufactured by Flynn & Emrich (Baltimore).

f. Mechanical Grates: Continuous Operations

Mechanical constant-flow grates have been, and are being, used in most of the newer continuous burning incinerators. This constant-flow grate feeds the refuse continuously from the refuse feed chute to the incinerator furnace, provides movement of the refuse bed and ash residue toward the discharge end of the grate, and does some stoking and mixing of the burning material on the grates. Underfire air passes upward through the grate to provide oxygen for the combustion processes, while at the same time cooling the metal portions of the grate to protect them from oxidation and heat damage.

(1) Reciprocating Grate. The reciprocating or pusher grate (Figure H-1), as manufactured by Detroit Stoker Company and Von Roll, is installed stepwise in rows on a slight downward incline toward the discharge; the rows move alternately to convey the refuse from the feed chute through the combustion area to the ash hopper. Although there is some stoking action as a result of the separate motion of the alternate rows of grates, additional stoking and mixing are obtained by providing a drop-off for tumbling from one grate section (step) to the next. Two, three, or four grate sections are commonly included in this type of grate for a continuous flow incinerator.

The reverse acting reciprocating grate (Martin) is also inclined downward, though at a steeper angle, toward the discharge end (Figure H-5). In this system, the cast metal grate elements reciprocate uphill against the downward flow of refuse, thereby producing some rolling of the burning material as a result of the upward reverse thrust. Again, these grates form a steplike configuration rather than a steady incline, so that additional mixing is obtained as the refuse tumbles from one level to the next.

(2) Rocking Grate. The rocking grate (Flynn & Emrich; Figure H-6) also slopes downward from the feed towards the discharge end, with two, three, four, or more grate sections installed in series with or without a drop-off or spill-off between grate sections. The rocking grate includes a multiplicity of grate sections or segments which are approximately quarter-cylindrical and which include openings for undergrate air. These grates are arranged as successive stair treads with risers of less than 1", and assembled to provide an inclined grate surface.

Alternate rows of grate sections are rotated approximately 90° about the edge toward the discharge of the grates, with the grate face rising up into the burning mass and thus breaking it up and thrusting it forward toward the discharge. These grate sections each rotate back to a rest position and alternate sections rotate as before, causing a similar stoking action and pushing of the refuse bed forward. This two-cycle action is similar to the previously described pusher and reverse acting grates, except that it seems to mix the material more effectively. Further, it redistributes the refuse and ash on the grate to cover local areas where burning has left some grate surface exposed.

(3) Vibrating, Oscillating, and Impact Grates. Another incinerator grate classification consists of the vibrating or oscillating grate and the impact grate. The vibrating or oscillating grate is mechanically powered by an eccentric-weight vibration generator or an eccentric-driven connecting rod. The oscillations convey the refuse through the incinerator furnace from one grate section to the next, in the same manner as an oscillating or vibrating conveyor. A similar, but non-uniform, oscillation cycle is used for the impact stoker or grate. The grate sections are moved either forward or in reverse and then released for spring return against a stop (impact). The grate surfaces are generally of the same type as used in the reciprocating grate elements, and, indeed, might be considered as a variation of the reciprocating type of grate. Although oscillating and impact grates have been used in fuel-burning furnaces and incinerators for many years, there are fewer of them than the other types of grates thus far described.

(4) Traveling Grate. The traveling grate is widely used in continuous flow incinerator furnaces. There are many installations in the United States, in Europe, and in Japan. Traveling grates are manufactured by many companies, including Combustion Engineering, Illinois Stoker, and Riley Stoker. The traveling grate has been in use for many years in coal-fired furnaces and, as in most grate systems, has been adapted for use in municipal incinerators. There are two types of traveling grate stokers: the chain grate and the bar grate. Both convey the refuse fuel from the gravity feed chute through the incinerator furnace to the ash residue discharge. (Figure H-7.)

Because the traveling grate stoker does not stoke or mix the fuel bed, incinerator traveling grate stokers are often cascaded in two, three, and even four or more units. With two units in cascade formation, the first portion under the feed chute and continuing through the ignition zone is often called the feeding or drying stoker. The discharge from this first portion of the traveling grate spills and tumbles onto a second unit, thereby mixing and redistributing the fuel bed on the second stage. With three or more stages, this spill-over and redistribution is repeated. Since the thickness of the refuse fuel bed decreases as the combustion process continues, the linear conveying speed of successive traveling grate units is adjusted to accommodate the rate of combustion and to provide more complete

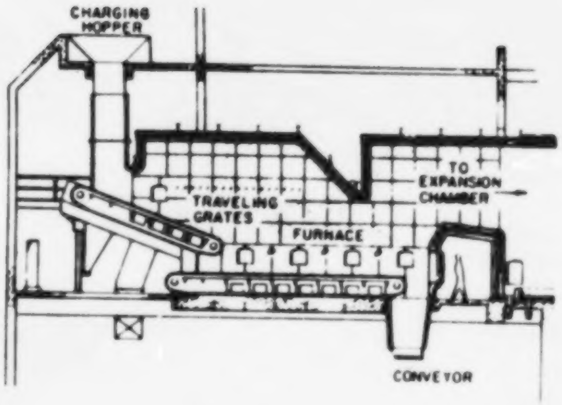
CHARGING HOPPER
TO EXPANSION CHAMBER
TRAVELING GRATES
FURNACE
CONVEYOR

FIGURE H-7

CONTINUOUS FEED TRAVELING GRATE INCINERATOR[1]

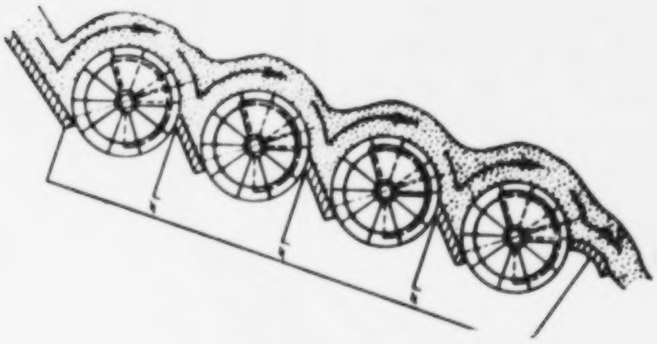

FIGURE H-8

DETAIL OF THE BARREL-TYPE GRATE[2]

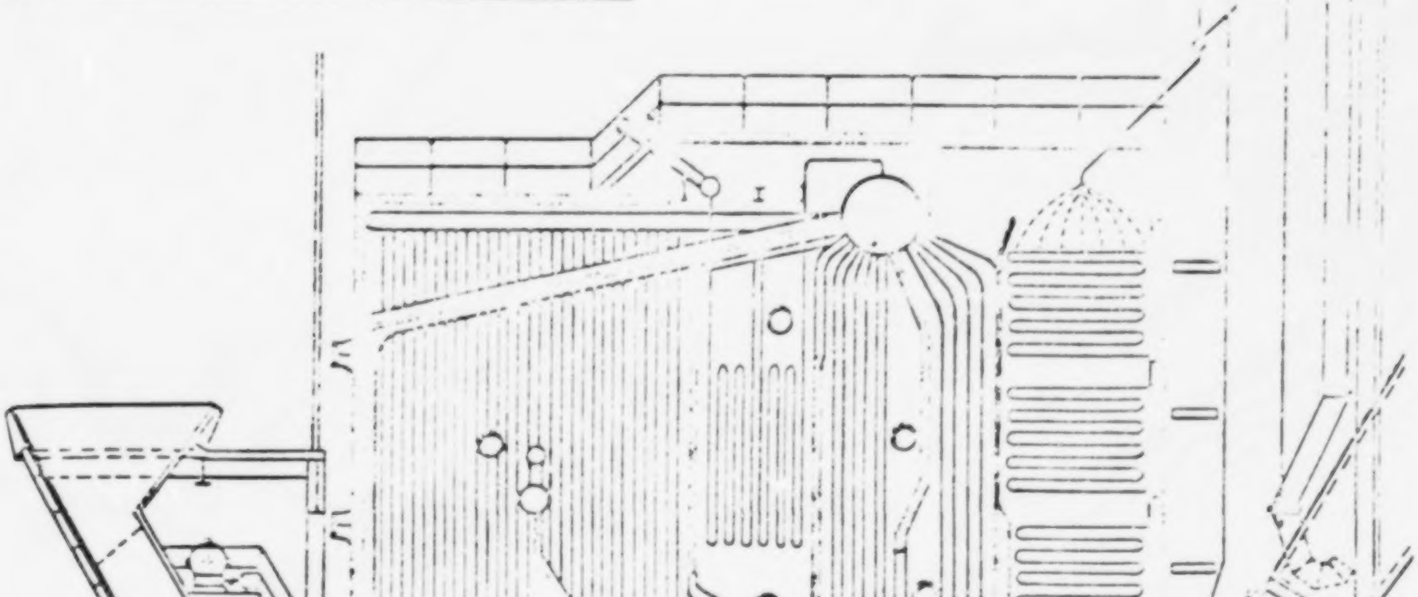

FIGURE H-9

BOILER WITH REVERSE-ACTING RECIPROCATING GRATE[3] burn-out after the combustion rate has subsided (decreased linear speed). Attempts have been made to install auxiliary mixing devices over the fuel bed on the traveling grate. However, these have not been successful, mainly because of entanglements with scrap wire and other debris contained in the refuse. The best method for stoking or mixing with the traveling grate is to use several grates so that stoking and redistribution is accomplished as the burning refuse is spilled from one section to the succeeding section.

(5) Drum Grates. The drum grate, or roller grate (sometimes called the barrel-type grate, Figure H-8), developed by the city of Dusseldorf, West Germany, was developed to counteract the high cost of multiple traveling grates needed to obtain better burnout. Each rotating drum or cylinder represents a minimum length of a traveling grate section, thereby providing a maximum number of tumbling zones in the fuel bed. This rotating grate system consists of six to eight or more rotating grate cylinders, 1.5 meters in diameter, mounted on a horizontal axis in close proximity and at a downward inclination of about 30°. The slow rotation of the drums creates a strong mixing action in the refuse between successive drums, thus loosening and opening bundles of paper or other compressed refuse. Each cylinder is formed from several single angular cast grate bars. The rotating cylinders extend over the width of the furnace (width of the grate) and each cylinder is equipped with its own variable-speed drive to control the movement of the burning refuse through the incinerator. Thus, the rotating drum grate provides improved refuse mixing or stoking during combustion, with better control and more complete burn-out.

g. Incinerator Stokers

Incinerator stokers are mechanical devices to burn solid refuse. A primary function is the conversion of chemical energy in the refuse fuel to thermal energy, which may be either wasted to the atmosphere as flue gas or in cooling water, or may be absorbed by boiler surfaces to produce hot water or to generate steam. Incinerator stokers must provide support and continuous or intermittent conveying of the refuse fuel bed, ignition of the refuse, adequate air for combustion, free passage for the gaseous pyrolysis products, and discharge of the noncombustible residue. Thus, the stoker is not only a conveyor, but a means to control the combustion process.

Although the process is visible and obvious, the real test of a stoker is its ability to consume the refuse fuel, release the thermal energy at a suitable rate, and dispose of the ash residue material with minimum complications.

Incinerator stoker sizes vary according to the rate of incineration of refuse in pounds per square foot of grate area per hour. (In reality, this weight-base scale of capacity is incomplete without a statement as to the heating value of the refuse.

By convention, however, stoker and incinerator capacities are expressed in weight-based units.) Considering various types of refuse and various proprietary designs of stokers, incineration rates vary from 40 pounds to 80 pounds per square foot of grate area per hour, and possibly upward to 100 pounds per square foot of grate area per hour.

In addition to the special mechanical action peculiar to the various stoker types, stoker grate surfaces are made with air openings in the castings for underfire air "leaked" through clearance between the grate sections, with "pinhole" air openings in the grate surfaces, with moderate air openings in the grate (as in the traveling grate) and with relatively large openings in the grate surfaces (as in the rocking grate). It is difficult to define any advantage for a particular size of underfire air opening without considering other interfaces, such as the air pressures and air distribution below the grate, the thickness of the fuel bed, and the degree of agitation or stoking of the fuel bed, since these and other related parameters may be more of a controlling factor than the size of the air openings.

The incinerator stoker is the principal item for control in the incinerator furnace system. It establishes the rate of refuse feed (in the continuous flow system), the rate of combustion, the residence time of the refuse in the combustion chamber, the completeness of the combustion or burn-out, the temperature of the combustion chamber, and even the temperature of the ash residue discharged from the system.

6. Incinerator Furnace Enclosures

The furnace enclosure provides a controlled environment for the combustion process in the incinerator system. Without the furnace enclosure, the combustion process would, in effect, be "open burning." If such burning is covered with a metal shield for protection from wind and direct radiation to the atmosphere, we have the conical burner which has been referred to as "a tent over a bonfire." However, the latter unit has the technical limitation that it must be operated with 300 to 600% air to prevent catastrophic heat damage to the metal structure and enclosure. Materials for conventional incinerator furnace enclosures include:

- Nonmetals (refractories, e.g., firebrick walls and roofs)
- Metal (plate, tubes, pipe, etc.)
- Refractory covered metal (castable or firebrick refractory lining or coatings, 1" to 9" thick)

Either water or air may be used to cool these enclosure materials. Cooling water can be either contained in tubes or pipes or uncontained in the form of a film on the surface of the external metal plate. Air cooling can be employed with forced convection; with forced air jets impinging on the surface; or by radiation and natural convection to the ambient environment. Warmed cooling air can be used as preheated air for combustion or can be ducted for building heat.

There are at least three types of refractory enclosures: gravity walls with sprung arch roofs; suspended walls and suspended roofs; and refractory linings supported directly by the metal shell. Gravity walls consist of refractories layed in courses, one above the other, supported on a foundation floor or other support, and are vertical (or almost vertical). The sprung arch used with gravity walls is a portion of a circular arch of refractory shapes supported by compression of the side walls through skew-backs retained with structural steel members held together with tie rods. Suspended refractories are supported on structural steel either directly with clamps attached to each piece of refractory, or with intermediate refractory pieces keyed or cast into the refractory roof being supported, with the refractory supporting member held with a metal clamp to the structural steel. Refractory linings are installed in a circular flue or duct and held like staves in a barrel, or if cast refractory is used, it is supported with metal hooks or dowels fastened to the shell by bolting or welding. Refractory walls can also be cast over pipes or steam tubes, thus protecting the metal tubes against corrosion or flame impingement, and at the same time cooling the refractory surface, with the tubes in turn cooled with hot water or steam.

A furnace enclosure infrequently used for municipal incineration is the rotary kiln. This is a near horizontal slowly rotating cylinder which may be lined with castable refractory or with large brick shapes called "kiln blocks." It is also possible to use an unlined rotary kiln cooled externally with air or water, or additionally cooled with a water film on the inside of the cylinder. This latter concept has only been applied in industrial incineration.

The use of waterwall enclosures is increasing. These enclosures are characterized as waterwall boilers or waterwall incinerator furnaces. Such walls are cooled by forced circulation of hot water or by natural convection as in steam boiler tubes (Figure H-9).

Furnace enclosures are subject to temperature changes, and refractory linings are susceptible to damage from spalling, fluxing and/or slagging. Spalling – the loss of fragments or spalls from the face of a refractory brick or structure through cracking and rupture, exposing the inner portions of the refractory mass – may result from stresses arising from unequal thermal expansion or contraction under rapid changes in temperatures (thermal spalling). It also may result from impact or pressure stresses (mechanical spalling). Fluxing is the melting and wastage of the refractory surface caused by the lowering of the melting point by changes in composition, such as the formation of a different chemical composition from contact with fly ash or other foreign material. Slagging is the accumulation of fly ash on the interior surfaces of the furnace, whether on refractory or on metal surfaces. This fly ash can sinter or fuse to form a slag coating. Slagging may cause fluxing of refractories or lead to wastage by spalling when the walls cool.

Corrosion must also be considered for any incineration furnace enclosure, whether refractory or metal. Corrosion of refractories is characterized by fluxing or change in chemical composition. Corrosion of metal may be of anyone or all of the following types: (1) condensation corrosion, usually caused by acid constituents which condense on the metal surface if the metal surface is below the dew point; (2) high-temperature gas corrosion, characterized by oxidation or carburetion reactions or by reaction with halogen, sulfur and the like; and (3) high-temperature liquid corrosion, resulting from the fusion of metal oxides and other compounds which react with the metal chemically and cause a wastage (similar to fluxing of refractories).

Another important aspect of furnace enclosures is air leakage control. Refractory walls and roofs can permit air to leak in or furnace gases to leak out depending on the draft conditions in the furnace, unless air-tight metal enclosures are used. Such leakage is particularly common with suspended refractory construction. It can be a benefit in providing air cooling of the wall or roof material, with inleakage of air adding to that required for combustion. In many installations, however, the inleakage of air can be excessive to the point that furnace temperatures are reduced, combustion of the furnace gases is quenched, and air pollution control systems are overloaded.

The physical shape of the furnace enclosure is a factor in controlling incineration process. For example, there is a tendency for hot combustion gases to rise to the top of the chamber. If the furnace outlet is at the top of the enclosure, the cooler gases from the discharge portion of the grate will leave the furnace below the layer of hotter combustion gases, often without mixing. Thus, a large fraction of the combustion air is not used and the flue gases may contain excess air as well as unburned combustible. This problem is reduced somewhat with chamber designs which exhaust the gases from the incinerator furnace either at the top near the refuse feed or at the lower portions of the furnace near the ash discharge. The installation of overfire air jets, refractory baffles, or bridge walls will also aid mixing.

The volumetric heat release rate characterizes the combustion intensity and wall temperature level in the furnace enclosure. Although designs vary, most refractory furnaces fall within the range from 15,000 to 25,000 Btu/hr cu-ft with an average of 20,000. This compares unfavorably with stoker-fired coal boilers which operate at 30,000 to 35,000 Btu/hr cu-ft. Although not yet proven, refuse fired waterwall boiler systems, both grate and suspension burning types, may be able to operate in the same heat release range as coal-fired boilers, because of the ability of waterwalls to absorb more heat per unit time without overheating. If so, this might make it possible to increase the rating of existing plants and decrease the unit furnace investment costs for new plants.

Many design specifications require a separate secondary combustion chamber with the incinerator installation. While the primary combustion chamber may be defined as the ignition, volatilization, and burning zone above the incinerator grates, the secondary combustion chamber or zone may be either a separate downstream chamber or an additional furnace volume downstream of the grate area. In either case, the secondary combustion zone provides suitable residence time for completion of the gas phase combustion reactions. This secondary zone should be located downstream of the point at which additional air is mixed with the furnace gases to supply oxygen for the completion of the combustion. The temperature of the secondary combustion chamber should be maintained above 1500 to 1600°F to insure complete oxidation of smoke (carbon and tar particles), hydrocarbon vapors, and combustible particulate and gases (such as carbon monoxide). A tertiary chamber is sometimes added downstream of the secondary chamber to provide additional combustion time, to provide for flue gas cooling and settling of fly ash, or simply to provide a flue gas connection from the secondary chamber to the breeching and stack.

7. Combustion Air

For incineration, the term combustion air usually includes underfire air, overfire air, and secondary air. However, these terminologies apply to incinerators employing grates in the system to support and/or convey the burning refuse through the incinerator. While combustion air for nongrate systems will be discussed later, underfire air for grate systems is defined as the air supplied upward through the grates and beneath the burning refuse. Underfire air is required to cool the grates (to maintain their structural integrity and to avoid oxidation corrosion of the grate metal). Underfire air is also supplied to furnish oxygen for the combustion reaction; it may be insufficient for complete combustion, yet sufficient to release enough heat to pyrolyze the refuse and remove the volatile components. Although it is common practice to pass a quantity of underfire air theoretically sufficient for complete combustion of the refuse on the grates, poor air distribution vis-à-vis the distribution of air demand, and poor gas mixing requires additional air as overfire or secondary air for mixing and for dilution of the gases to maintain temperatures below 1800°F to 2000°F, respectively. Underfire air is required in the later stage of the batch process (or further downstream in the continuous process) for oxidation of the remaining fixed carbon in the ash residue to provide complete burnout.

Overfire air may be defined as that air admitted above the burning bed of refuse on the grate. It is usually admitted either in low- or high-velocity jets to mix the combustible gases rising from the burning refuse with combustion air. Secondary air, added for temperature control, may be admitted through high-velocity jets in the side walls and roof of the furnace enclosure, either near the upstream end of the primary furnace or at the transition between the primary and secondary furnace. Also, secondary air can be added at low velocity through a slot or small openings in the bridge wall separating the primary chamber from the secondary chamber. In the latter case, mixing is dependent more on the shape of the chamber and changes in direction of the main gas stream, than on the energy carried by the air jets.

Centrifugal fans with electric motor drives are used to supply combustion air. Since the fans for high-velocity combustion air must operate at higher tip speeds and therefore with considerable noise, the fans should be located where their noise will not be a nuisance. In general, sound absorbing devices should be considered on these and other high-speed fans.

Low-velocity combustion air can also be admitted through louvers, doors, or other openings as a result of the negative pressure or draft within the furnace chamber. The quantity of combustion air admitted through such openings can be controlled by dampers or by the door opening.

Combustion air for suspension burning, without main grates, requires a different consideration from combustion air for a grate system. In suspension burning within a waterwall furnace or within a refractory furnace, the air that conveys the shredded refuse into the chamber may be half or all of the theoretical air required for combustion; however, it must be sufficient to convey and inject the shredded refuse into the furnace. It is also desirable to add air at points in the furnace chamber in a tangential pattern to create a cyclonic action, with the burning mass in the center of the rotating cyclone and the air injection surrounding the cyclonic flame. If the suspension burning system includes an auxiliary grate at the bottom of the furnace chamber for completing the burnout of the ash residue, a small amount of underfire air is desirable through this grate. Although high-speed centrifugal fans in single or multiple stage can be used to supply the air for injection of the shredded refuse for suspension burning, positive displacement blowers can also be used for injection air as well as for high-velocity tangential air jets to induce mixing within the cyclone of flame in the furnace.

8. Ash Removal

After complete incineration of the refuse the ash residue drops into an ash chamber or chute from the end of the grate or kiln. Siftings that have fallen through the grates (which may have been either partially or completely oxidized) and collected fly ash also may be conveyed to this ash chamber. The ash may be discharged directly into a container or onto suitable conveyors for disposal, or into water for quenching and cooling. The ash residue is then removed from the water with a drag conveyor, pusher conveyor, or other means. Rubber belt conveyors have been used in Europe for some time on water-quenched ash residue and there are now a few installations in this country. Pneumatic and hydraulic handling could, perhaps, also be used, as in the handling of the ash from the combustion of coal after it has been burned under steam boilers. Alternatively, the ash residue can be handled manually from the ash hopper by discharging into a dump truck or other suitable container and transported to the residue disposal site or serviced to by-product recovery systems.

To prevent inleakage of air or outleakage of furnace gases at the point where the gas is removed, an air seal is desirable. Dry mechanical seals and seals made by covering the ash receptacle or container have been used to control air leakage. With wet removal of the ash, a wet or hydraulic (water) seal is utilized or a combination of a wet and mechanical seal is used (Martin ash quencher seal). The ash residue usually includes abrasive and corrosive materials and miscellaneous slag and metal. Therefore, to avoid malfunctions, metal pieces, such as coat hangers, cans, metal hoops, and occasional large and heavy pieces of wood or metal, must be carefully considered in the design of equipment which handles ash residue.

In connection with the disposal of the ash, a number of installations include recovery of salvageable materials before the remaining ash is conveyed to the dump or disposal site. Such recovery systems include rotary screens (trommels), vibrating screens, crushing or shredding devices, as well as ballistic and magnetic separation equipment. Through the use of these devices, ferrous metals can be removed for salvage as scrap; medium ash solids, such as clinker particles, portions of fused glass, or particles of shattered glass, can be removed for use as fill material or for use in surfacing and construction of alleys and secondary streets; the fine ash which has no salvage value is transported to the dump site for disposal by truck or by means of a belt conveyor or a hydraulic system.

The oversize noncombustible in the ash residue from the incinerator furnace is customarily transported to the dump site for disposal. In a few instances, oversize noncombustible is passed through crushing or breaker rolls which flatten larger metal pieces and crush nonmetal pieces. The material that has been reduced in size may be passed over a magnetic separator to remove iron for scrap salvage.

9. Flue Gas Conditioning*

Inasmuch as the incineration of municipal refuse is a combustion process, it is necessary to remove the heat that is generated. In the past, this has usually been done with a gravity stack which, except for the heat lost through the incinerator walls, discharged most of the combustion energy to the atmosphere as sensible heat in the hot flue gases. The heat of evaporation of moisture in the refuse and from cooling of flue gases by water sprays is discharged as latent heat of the water vapor in the flue gases.

In some of the early incinerator designs, the combustion gases were carried directly to the stack through the breeching and flue without the use of any air pollution control equipment and without the use of an induced draft fan, since the stack provided the necessary draft for the incinerator furnace system. The amount of draft produced by the stack or chimney depended on the temperature of the flue gases entering the chimney; in order to obtain ample draft, as well as to reduce the height of the chimney, it was desirable to operate with a maximum flue gas temperature.

Early attempts at flue gas conditioning used a settling chamber in the breeching, sometimes with refractory baffles or hurdles to cause the gas to change direction and thus remove the larger and heavier particles. Water sprays were often used in an effort to wash some of the larger particles from the gases. With the need for better air pollution control equipment, it was necessary to install induced draft fans to overcome the pressure drop through the baffles, cyclones, or other air pollution control equipment, and it was then necessary to reliably condition or cool the gases to a temperature below 600°F-700°F. The upper limit of this flue gas temperature is dictated by the temperature carbon steel can withstand without loss of tensile strength and without oxidation corrosion of the metal. The significant cost savings realized by use of carbon steel as a material of construction (vs. high nickel-chromium stainless) made this operation necessary and economically justifiable.

Cooling of the flue gases is accomplished by one or a combination of any of three methods:

- By direct injection and vaporization of water;
- With a heat exchanger, such as a waterwall or convection boiler, air-cooled refractory, or an air preheater; and
- By dilution and mixing with cool atmospheric air.

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*See also Appendix B.

Evaporative cooling systems vary widely in design according to the equipment downstream and whether or not air pollution abatement is a parallel objective. Large droplet sizes (low-pressure nozzles) are usually used for particulate control or with wetted baffle impingement devices. Fine droplets (high pressure nozzles) are used frequently when flue gas cooling is the only function of the sprays, especially when "dry bottom" operation is desirable. In some plants, water evaporation occurs in the air pollution control devices themselves as with wet scrubber systems. In all cases, sufficient time must be provided after water contacting to assure dry flue gas conditions before entering dry particulate collectors or fans.

In addition to the normal heat losses by conduction through the walls of the furnace chamber, more recent installations have utilized waterwall boilers for the furnace enclosure, and one or more convection passes for additional heat recovery. The use of a conventional boiler alone has been practiced since 1927. It is alleged that the waterwall boiler furnace permits the use of lesser amounts of excess air than are required to cool refractory furnace chambers to avoid fluxing and slagging of walls. However, even with waterwall boiler construction, there can be slagging of fly ash on the tubes as well as corrosion of the waterwalls and the convection boiler tubes as previously discussed.

In an effort to reduce the capital cost of the incinerator and to provide cooled walls to enable operation at low amounts of excess air and thus reduce the size of the air pollution control equipment required, air cooling of the refractory walls and roof of the furnace chamber is being considered. With such air-cooled wall systems, the cost of an incinerator operating under low excess air conditions may be less than the cost of a waterwall boiler furnace. An air-cooled refractory furnace would be desirable where it is either difficult or impossible to utilize the steam generated from the incineration process. With air cooling, the furnace enclosure heat load could be transferred directly to the atmosphere.

Although an air preheater is not used except in a few instances where it is necessary to preheat air for combustion in order to incinerate wet refuse, indirect air cooling with a gas-to-air heat exchanger can be used as a method for heat recovery, such as for building heating, with the unused hot air exhausted to the atmosphere. Flue gases can also be cooled with a heat exchanger to reheat saturated flue gases from a water scrubber to avoid a steam plume from the top of the stack.

The deliberate use of air dilution for cooling flue gases to 600-700°F has not often been used; although some cooling effects are naturally realized by the admission of excess combustion air in the furnace or by leakage through cracks and openings in the walls of the furnace, the breeching and the flues. In general, dilution cooling with air is the least desirable method for flue gas conditioning because it produces the greatest increase in volume of flue gases that must be handled by the air pollution control equipment, the induced draft fan and the stack, thereby increasing the size and cost of all of these elements.

10. Air Pollution Control

Although the flue gases from incinerators contain a number of pollutants, all air pollution control (APC) equipment installed on these units address the problem of particulate removal. For this purpose, a number of devices are in use, ranging in particulate removal efficiency from 5-15% to upwards of 95%.

Settling chambers or expansion chambers have been used in the breeching and flue gas ducts and many of the older installations have employed refractory baffles across the breechings extending downward from the roof or upward from the bottom of the breeching to require the flue gases to pass under and over such baffles. In some instances, a coarse spray of water is directed into the flue gases and toward the baffles with most of the water falling to the floor of the chamber without vaporization. The wet floor and baffles improve particulate removal by preventing reentrainment of settled ash into the flue gas stream.

Mechanical collectors are usually "cyclones" in which the flue gas is rotated within the confines of a cylinder after entering tangentially at the periphery. The flue gas then leaves through an axial outlet. Solid particulate concentrates on the inside of the cylindrical wall (as a result of centrifugal force) and solids are discharged at the lower end and opposite to the cleaned gas outlet. Listed below in order of increasing APC effectiveness (and pressure drop) are three general types of such cyclones:

- A multiple cyclone with many small diameter (less than 12") cyclone units installed in a tube sheet;
- A multiple cyclone system of larger diameter (over 18") installed in clusters with flue gas manifolded to the inlets of the individual cyclones and the outlet manifolded into a single duct;
- Single or double cyclone units of larger diameter (over 4') with a single or split flue duct at the inlet and outlet.

Other devices used for particulate removal from flue gases include scrubbers, which may be open spray chambers, packed chambers and high-pressure drop units (e.g., Venturi scrubbers). Filters used for particulate removal are mainly those of high-temperature fabrics, such as silicone-treated glass fiber cloth, arranged in bags or tubes. Another type of filter is the fixed bed unit, which has had long experience in the metallurgical industries for cleaning of gases at high temperatures, although it has not been utilized in connection with particulate removal from incinerator flue gases.

A common, though only moderately efficient, type of air pollution control concept for cleaning incinerator flue gases is the use of vertical staggered baffles which may be employed in multiple stages in a group, or with groups of baffles in each stage. These baffles are wetted with water, either by a spray application or by overflow from the top of a tall metal tank (Detrick-Jens). Although most of the staggered baffles which are wetted with a water-spray are constructed with refractory firebrick, a few are installed with corrosion-resisting metal baffles, such as special stainless steels.

The electrostatic precipitator is currently receiving increased attention for particulate removal from incinerator flue gases. At the time of this writing, there are a few electrostatic precipitators in the installation stages or nearing completion in this country. There are no electrostatic precipitators on incinerators in the United States with operating experience, although a number of European incinerators have utilized electrostatic precipitator gas cleaning for many years. These European installations were originally employed on combination power plants and incinerator furnaces, although recently there have been a few electrostatic precipitators installed on steam boiler plants in Europe which are exclusively fueled with municipal refuse. Electrostatic precipitators used for cleaning incinerator flue gases are the vertical multiple-plate-type; tube-type precipitators have not been used on incinerators, nor are they contemplated for use.

A more complete description and performance analysis of cyclone collectors as well as all types of air pollution control devices is included in Volume I, Section VII B of this report.

11. Incinerator Stacks

Several types of stacks or chimneys are used to discharge incinerator flue gases into the ambient atmosphere. Stub stacks are usually fabricated of steel and extend a minimum distance upward from the discharge of an induced draft fan. Stacks taller than about 5 diameters and less than 100 feet high are often referred to as "short" stacks. These are either constructed of unlined or refractory lined steel plate, or are constructed entirely of refractory and structural brick. "Tall" stacks are constructed of the same materials as the short stacks above, and are used to provide greater draft than that resulting from the shorter stack, and to obtain more effective diffusion of the flue gas effluent. Some metal stacks are made with a double wall with an air space between the metal sheets. This double wall provides an insulating air pocket to prevent condensation on the inside of the stack and thus avoid corrosion of the metal.

12. Control

The control facilities for a municipal incinerator installation fall into two classes. One includes refuse weighing and accounting equipment; communication equipment such as phones, intercoms, signals and alarms; hydrants, hoses and sprinklers for fire control; spraying systems for odor control; and insecticides and rodenticides for vector control. The other classification includes process control and the instrumentation associated with process control. In this category, indicating, controlling and/or recording devices are desirable for measurement of temperature and pressure; mass flows of air, flue gases, water, steam, refuse and residue; for measurement of smoke; and for analyzing the flue gases.

These instruments and their functions are included in Table H-1. The selection among the large number of devices listed depends upon the sensitivity of the plant to fluctuations in various parameters, the degree of automation desired, etc. In general, most existing incinerators suffer from too few such devices (installed, functioning or effectively used) rather than too many.

In order that control instrumentation may be utilized to maximum advantage, as well as provide reliable information for control, it is vitally necessary to have an adequate instrument maintenance program. Since the usual incinerator staff does not include instrumentation specialists, the maintenance of the process control instruments should be provided through a maintenance contract with the instrument vendor. Such a contract will permit maximum utilization of the process instrument data, as well as provide the lowest cost maintenance for the instrumentation equipment.

13. Waste Water Disposal

Waste water may be produced at incinerator installations from chamber sluicing, the quenching of ash, the ash conveyor seals and other parts of the ash conveyor system, the flue gas cooling chamber, and from the flue gas scrubbers. Because of the possible water pollution problem and the costs of water treatment facilities, this waste water flow is often minimized. Ash quenching can be performed with air near the discharge end of the grates or in a separate ash cooler. In some plants, dry ash and siftings conveyor systems are used. Gas cooling may be accomplished with a convection boiler, a gas-to-air heat exchanger, or by total evaporation of fine water sprays. Dry dust collection systems are also used (such as the mechanical cyclone and electrostatic precipitator) to avoid producing contaminated waste waters.

In the event that waste water is produced (most incinerator installations), the water should be passed through a treating process before discharge from the incinerator site to avoid stream pollution and/or to avoid the requirements for

TABLE H-1

PROCESS CONTROL INSTRUMENTS

Variable	Instrument Type*
Temperature	
Feed chute	I, R, alarm for high temperature
Windbox undergrates	I, R, alarm for high temperature
Furnace at gas outlet	I, R
Combustion chamber (or secondary chamber)	I, R, C (C for excess air)
Convection boiler gas outlet	I, R
Flue gas conditioner gas outlet	I, R, C (C for water flow)
Air pollution control outlet	I, R, alarm for high temperature
Stack inlet	I, R
Feedwater to boiler	I, R, C (C for heater)
Pressure (also draft)	
Underfire air (zones 1, 2, 3 . . . n)	I
Overfire air (zones 1, 2, 3 . . . n)	I
Furnace chamber	I, R, C (C for draft control from ID fan)
Combustion chamber outlet	I
Convection boiler gas outlet	I
Flue gas conditioner gas outlet	I
Air pollution control outlet	I
Induced draft fan discharge	I
Steam at boiler header	I, R, C (control of auxiliary fuel)
Feedwater	I
Plant water	I
Water to flue gas conditioner	I (control from temperature)
Water to air pollution control device	I

* I - Indicating
R - Recording
C - Controlling

TABLE H-1 (Continued)

Variable	Instrument Type*
Flow	
Underfire air (zones 1, 2, 3 . . . n)	I, R
Overfire air (zones 1, 2, 3 . . . n)	I, R (control from temperature)
Total air for combustion	I, R
Flue gas at I. D. fan	I, R
Water (to flue gas conditioner)	I, R (control from temperature)
Water (to air pollution control device)	I, R
Feedwater	I, R, C (from water boiler level control)
Steam (to header)	I, R
Refuse feed	I, R (from integrator on crane bucket)
Residue (ash)	I, R (from weight on ash conveyor)
Grate speed (refuse feed)	I, R
Auxiliary fuel	I, R, C (control from steam pressure)
Smoke	
Smoke density meter	I, R (alarm for high smoke desnity)
Flue Gas Analyzer	
Oxygen	I, R, C (control feedback to overfire air)
Carbon dioxide	I, R
Carbon Monoxide	I, R (alarm for high CO)
Combustible	I, R (alarm for high combustible)

* I - Indicating
R - Recording
C - Controlling

added sewer and treatment plant capacity resulting from discharges into the municipal sewer. Often, unfortunately, no treatment is applied. Preliminary treatment by settling in a controlled pond or a series of tanks is considered a minimum treatment of waste water from the incinerator. In addition, pH control of the water leaving the settling pond is desirable. If the water is recycled from the settling pond, it is desirable to control the water to neutralize any acidity, in order to avoid corrosion of the pumps, piping and the system using the recycle water. If the settling pond holding time is inadequate such that the water is not sufficiently clarified at the settling pond overflow, coagulation and/or filtration of the effluent may be indicated in order to provide clear water for recycle and overflow.

After suitable treatment by settling, pH control, coagulation and/or filtration, disposal of the waste water may be accomplished through a drainage ditch, stream or other flowing surface water. In a few areas, the properly treated waste water can be allowed to soak into the surrounding soil. In order to minimize the quantity of overflow water for disposal, it is desirable to recycle as much water as possible, and approach a total usage of water. However, even in a closed system, it is usually necessary to bleed off a small quantity of waste water to prevent a concentration buildup of soluble salts. Although there is no known application of this principle of total recycle in municipal incinerators, it is technically feasible to evaporate the bleed water and thereby make a total use system. Such a total utilization system for water is common practice in certain of the chemical processing industries and would be easily adapted to incinerator processing because of the waste heat available with incineration. Some or all of the bleed water can be mixed with the refuse, whereby the dissolved solids would be removed with the ash residue.

14. Site Requirements

Site requirements include access and egress from the incinerator which is usually by roadway although rail transportation and canal or river transportation by barge are also feasible. Landscaping and parking facilities comprise another element of site design. Usually, parking facilities can be provided with ease. However, inadequate landscaping effort is often the cause of poor public relations subsequent to plant start-up.

The topography of the site can be arranged by grading of the natural terrain. It is unfortunate that most incinerator installations are in undesirable low-lying areas adjacent to dump sites. With the development of total incineration methods producing sterile, nonodorous slag instead of "bonfire ash," more consideration can be given to normal elevation or even hillside sites for incineration. The use of low-lying or low elevation sites causes difficulty in dissemination of effluent gases and potential air pollution; with installations at higher elevations, the flue gases are more easily distributed into the atmosphere with quicker dilution.

Finally, the site must include an area for residue disposal. This is commonly known as the dump area, and is used for the disposal of oversize noncombustible materials, incinerator ash residue, and for large pieces of trees and wood timbers from building demolitions. Such a residue disposal area is desirably located adjacent or as near to the incinerator as possible to reduce transportation costs. While most incinerator dump sites are operated on the basis that the incinerator ash residue is inert and stable, this is unfortunately not usually the case. As a result, some incinerator dump sites are operated as a sanitary landfill with frequent covering of the residue.

As a result of such poor residue quality, vector control for extermination of rats and prevention of breeding of flies, mosquitoes and other undesirable insects is often needed and sometimes practiced. The prevention of large accumulations of gulls and other scavenger birds is more difficult to control except by operation of the site as a sanitary landfill, together with incinerator operation to assure complete burnout of combustible material in the incinerator ash residue.

15. Buildings

The building around a municipal incinerator should provide weather protection for the operators, should control spillage such as wind-blown refuse and ash, provide office space for incinerator management and supervision, and convenience facilities for the operating personnel (such as lockers, washrooms and lunchrooms). In addition, space should be provided for the maintenance shop, storage of spare parts, storage of mobile equipment and housing for utilities including heating and ventilation equipment. Heating and ventilation should be adequate for the health of the operating personnel.

The traditional design of buildings for municipal incinerators has developed a "public building" type of structure rather than a structure to house a manufacturing or operational facility. Such architecture contributes to the aesthetic qualities of the plant, but may be disadvantageous to the functional characteristics of the plant and increases the plant cost. In most installations, the building alone comprises 30-40% of the plant cost. In comparison, industrial buildings usually comprise 20-30% of the plant cost.

16. Utilities

The municipal incinerator installation requires utilities for electric service, for water supply, and for fuel for space heating and for equipment. The electric utilities include a substation, a distribution transformer, distribution switch-gear and motor control units. In several European plants, which include electrical generation, plant power is self-supplied. In plants generating steam, a portion of the plant's fans can be driven with steam turbines instead of electric motors.

Water supply for the incinerator can be provided from the city water mains. Such water quality is necessary for human consumption but may not be required for many incineration uses. In some areas, in consideration of the cost of city water, the cost of water for incineration process applications is reduced by the use of wells or natural areas adjacent to the incinerator. Water treatment facilities are limited since the water would not be used for human consumption. Some applications, however, such as boiler feed or water for high-pressure atomizing nozzles, may require special treatment.

The uses for fuel and the types of fuel required for an incineration installation fall into two categories: space heating, including natural gas, fuel oil, and coal; equipment operation, including gasoline and diesel fuel.

C. PRINCIPLES OF THE INCINERATION PROCESS

Refuse is a fuel, although a difficult one to handle. Incinerators are combustion systems, which obey the same fundamental laws as a modern power boiler or a jet engine. This view of municipal solid waste disposal by incineration is as powerful as it is obvious. As long as refuse and incineration carry a mystique, as though altogether different from other fuels and combustion processes, the technology of incineration will remain primitive, and the problems of the past will remain both puzzling and unsolved.

The purpose of this portion of the report is to give the reader perspective as to the common and unique combustion characteristics of refuse and to briefly describe the fundamental heat and mass transfer and chemical reaction processes important in incinerator combustion. This description is not comprehensive, but it suggests the extent of our present understanding of the process as reflected in past studies on comparable systems. The interested reader is strongly urged to pursue the subject more deeply in the references given and in other combustion and furnace design texts.

In spite of expenditures of many millions of research dollars over the past 100 years, combustion theory is still unable to quantitatively describe the burning processes in a candle flame. However, the efficiency and reliability of contemporary coal-fired boilers are a direct result of pragmatic engineering application of combustion theory. The theoretical descriptions of furnace processes presented below, therefore, should be considered as tools to provide insight when interpreting behavior and as guides to improve design, not as unvarying laws.

1. Refuse as a Fuel

Electric power plants and industrial combustion systems represent a rich source of data and proven design experience for understanding and improving incineration systems. To use these data, however, it is necessary to appreciate the similarities and the differences between refuse and refuse combustion parameters and those of other fuel types.

a. Heat Content

Refuse, though quite different from high-rank coals and oil, has considerable similarity to wood, peat and lignite (Table H-2). It would be reasonable, therefore, to seek incinerator design concepts in the technology developed for the combustion of the latter materials. Refuse does, however, have distinguishing characteristics, such as its high total ash content, which may require more extensive ash handling equipment. Excluding the massive ash (metal and glass), however, the ash content is only 5.44%, suggesting that incinerators may require less efficient air pollution control devices for comparable combustion situations. Clearly, refuse is also a lower energy fuel than most conventional alternatives.

b. Density

Refuse density is similar to that of wood, peat, and lignite (Table H-3). Since coal and refuse furnace retention times are comparable (40-50 minutes), refuse bed depths would be much greater than those for coal at comparable grate burning rates. A typical coal stoker, for example, burns at the rate of 400-500 M Btu/hr sq ft. This corresponds, for the bituminous coal energy density and for typical stoker speeds, to a bed height of 5 to 7 inches. In order to provide comparable specific burning rates for refuse, bed heights from 3.6 to 5 feet are required.

Table H-3 indicates the average density of the refuse in comparison with other fuels. The "ultimate density" for refuse was calculated as the weighted sum of the densities of the refuse components. Comparing the "ultimate" density with the "as-fired" density yields an approximate void fraction which is much higher for refuse than for any other fuel shown. The high void fraction, aside from re-affirming the need for a deep bed, also indicates the difficulties in obtaining uniform refuse distribution to avoid "blow-holes" or open spaces on the grate.

c. Air Requirements

Although the refuse air requirement per million Btu is in line with the others, refuse has a relatively low air requirement per pound of fuel (Table H-4). Since refuse is now burned at bed depths which approximate coal heat release

TABLE H-2

HEAT CONTENT OF REFUSE AND OTHER FUELS

				Btu/lb (Higher Heating Value)				
Fuel	Moisture	Ash	Volatile (Dry Basis)	As-Fired	Ash-Free	Dry Basis	Dry, Ash-Free Basis	(Lower Heating Value) As-Fired
	%	%	%					Btu/lb
Refuse	28.16	20.82	62.3	4,450	5,620	6,195	8,720	3,935
Wood	46.9	1.5	78.1	4,690	4,760	8,835	9,090	3,910
Peat	64.3	10.0	67.3	3,235	3,595	9,057	12,590	2,390
Lignite	36.0	12.1	49.8	7,065	8,040	11,038	13,610	6,450
Sub-bituminous B	15.3	6.7	39.7	10,245	10,980	12,096	13,135	9,675
Bituminous – Hi Volatile B	8.6	8.4	35.4	12,235	13,355	13,388	14,740	11,735
Bituminous – Volatile	3.6	4.9	16.0	14,460	15,205	15,000	15,805	13,990
Anthracite	4.5	14.4	7.4	11,100	12,970	11,624	13,685	10,820
Methane	0	0	100.0	23,895	23,895	23,895	23,895	21,555
#2 Fuel Oil	0	0	100.0	19,565	19,565	19,565	19,565	18,375
#6 Fuel Oil	1.5	.08	100.0	18,265	18,280	18,545	18,675	17,280

TABLE H-3

DENSITY OF REFUSE AND OTHER FUELS

Fuel	Density (as fired) lb/cu. ft.	MBtu/ft^3	Density (ultimate) lb/ft^3	Mean Void Fraction
Refuse	17. (ave)	76	60 (est)	72%
Wood (Chips)	17.5	82	35 (ave)	50
Peat	25. (est)	80	50	50
Bituminous Coal (sized)	50.	650	87.5	43
#6 Fuel	61.5	1125	61.5	0
Methane	0.042	1	N/A	N/A

TABLE H-4

THEORETICAL AIR REQUIREMENTS OF REFUSE AND OTHER FUELS

Fuel	Lb Air/Lb Fuel	Lb Air/MM Btu	scf Air/M Btu
Refuse	3.22	724	9.77
Wood	3.29	703	9.49
Peat	2.33	722	9.75
Lignite	5.27	746	10.07
Sub-Bituminous B	7.58	740	10.00
Bituminous High Volatile	9.08	742	10.01
Bituminous Volatile	10.99	760	10.26
Anthracite	9.23	831	11.22
Fuel Oil	13.69	750	10.13
Methane	17.26	722	9.75

rates (Btu/hr sq ft), the air rates (cfm/sq ft) could, in principle, be similar to those used for coal stokers. In practice, however, much higher air rates are used in incinerators to effect drying and to temper ultimate combustion temperatures.

d. Summary

In summary, refuse burning practices should be comparable with those for low rank carbonaceous solid fuels such as wood, peat and lignite. Although incinerator designs reflect a portion of the technology developed to burn these other materials, application of spreader stoker and suspension burning techniques and some aspects of furnace design and fuel feeding have not yet found their way into conventional incinerator practice. However, refuse does present some unique problems to the furnace designer, particularly as a result of its relatively low energy density, high ash content, and high moisture content.

2. Grate Burning Processes

As with most solid fuels, refuse combustion is accomplished on a grate surface. Although a substantial fraction of the heat release takes place in the overfire volume, the grate combustion processes are of vital importance in obtaining adequate refuse burn-out with furnaces of reasonable size. Grate processes include: drying, ignition, pyrolysis residue burnout, and residue cooling.

a. Drying Processes

The high moisture content of refuse in comparison to bituminous coal (Table H-2) can contribute to differences in grate burning behavior, particularly as regards drying ignition. Bituminous coal with a 6-inch bed depth (25.00 lb/sq ft) presents a pre-ignition drying load of 2.1 pounds of water per square foot. In general, this moisture is superficial and much is removed by evaporation into the undergrate airflow. Refuse, however, with a 3.5 foot bed (60.0 lb/sq ft) requires the evaporation of 16.88 pounds of water per square foot. This moisture, in contrast to coal, is not uniformly distributed throughout the refuse, some components (especially food wastes) being quite wet, and other components being comparatively dry. The drying problem is compounded by compaction of refuse components to yield clumps with relatively high cross sections.

Refuse moisture content is important in controlling the rate of heat release along the grate. Wet refuse, which dries slowly, tends to spread out the burning process as the latent heat of evaporation slows the propagation rate of the ignition front through the refuse. Typically, wet refuse burning problems are moderated by increasing the underfire air rate. This air flow dries the refuse by evaporation and also intensifies the fire, somewhat as a blacksmith's forge, to increase the heat release rate in the bed. The resulting radiative heat transfer assists in drying the refuse ahead of the advancing ignition front.

Refuse moisture may also have a substantial effect on the gas composition leaving the refuse bed. It is commonly recognized that in grate burning processes where the undergrate air flow is less than stoichiometric, substantial amounts of carbon monoxide are formed by the producer gas reaction.

$$C + CO_2 \longrightarrow 2CO \qquad \text{(H-1)}$$

This reaction of carbon dioxide, formed in the lower parts of the bed, with the carbon residue at the surface of the bed is known to be important in grate burning of bituminous coal. It is suggested here that the water gas reaction, Equation H-2, may also be important in incineration practice where the evaporation of moisture within the bed and moisture from combustion increases the water vapor concentration of the gases flowing to the surface of the bed.

$$H_2O + C \longrightarrow CO + H_2 \qquad \text{(H-2)}$$

Few detailed experimental data are available on the concentration distribution of these species within a burning refuse bed. Work, however, is in process at a number of universities.

b. Ignition Processes

The isothermal surface in a fuel bed at which ignition occurs, defines the ignition front. Above this front, the temperature rises rapidly as energy is released by the combustion reactions. Below the front, the fresh feed is being heated by radiation from the burning zone. The relatively high attenuation factor in the bed limits the propagation rate of the front, thus accentuating the temperature gradient across the ignition surface.

Although a unique "ignition temperature" may not be a precise concept, in practice the ignition temperature for any given fuel, measured under a variety of conditions, probably falls within a range of 100°F. This narrow range is due to the high temperature sensitivity (high activation energy) of the heterogeneous combustion reactions. Although ignition temperatures have not been measured for refuse, the data in Table H-5 are shown for reference. Since the ignition process in refuse components may well be preceded by pyrolysis, the ignition characteristics of refuse volatile matter may be of more importance than that of the solid carbon residue. This relative importance has been shown to hold in studies of flame speed in pulverized coal flames.

TABLE H-5

APPROXIMATE IGNITION TEMPERATURES IN AIR[4]

Combustible Material	Temperature° F
Charcoal	650
Fixed Carbon (bituminous coal)	765
Fixed Carbon (semi-bituminous coal)	870
Fixed Carbon (anthracite)	840-1115
Ethane	880-1165
Hydrogen	1065-1095
Kerosine	490-560

The ignition front propagation rate is strongly affected by the undergrate air flow. At low flows, the ignition rate is slowed due to the endothermic formation of carbon monoxide by the producer gas reaction (re-capturing about one-third of the heat released in carbon dioxide formation), and by the generally lower heat release rates within the bed and on the surface of the carbon residue. As the undergrate air flow rates increase, the propagation rate increases until a peak is reached where the convective heat losses from the bed ahead of the ignition front exceed the radiative heat flow into the un-ignited material. It is likely, however, that the flow rates required to produce this latter condition exceed those found in incinerator practice.

c. Pyrolysis and Bed Burning

After, and perhaps as part of the passage of the ignition front, refuse pyrolysis takes place. This process, primarily heat transfer controlled, results in the formation of a complex mixture of partially oxidized hydrocarbon gases and tars and a solid char residue. Detailed discussions of several aspects of refuse pyrolysis and comparable experience with low-temperature coal carbonization are presented in Subsection VII-E6.

The combustion process in burning solid fuel beds has been studied both experimentally and theoretically by a number of researchers, particularly with reference to the combustion of coal on grates. The combustion of carbon with oxygen in the solid bed has been postulated by Thring[5], to take place in three stages. In the first stage, the solid, carbonaceous residue is attacked by oxygen to generate, mainly, carbon monoxide. In the second stage, the carbon monoxide, migrating into the spaces between the refuse elements, reacts in the gas phase with further available oxygen, to form carbon dioxide. In the third stage, the producer gas reaction (Equation H-1) results in the conversion of carbon dioxide into carbon monoxide. This reaction sequence has been observed in a number of experiments on coal and coke combustion. Clearly, the irregularities of a refuse bed may lead to emission of gases which have passed, to varying degrees, through this and competing reaction sequences.

A very elegant treatment of the heat transfer and chemical reactions taking place in fuel beds was conducted by Mayers[6]. His work was carried out originally to develop a theoretical model of fuel-bed burning for use in evaluation and coordination of experimental work. Although the complex equations and solutions (obtained by numerical methods) will not be reproduced here, this work provides a starting point for the development of mathematical analogs of burning in refuse beds. Also, experimental data by Kreisinger et al[7] on the reactions and temperatures in beds of burning lignite (similar, in many ways, to solid waste) may be useful as a reference.

One of the important parameters noted by Mayers was the rate of heat loss from the top of the burning surface. This was shown to be important, as a boundary condition, in defining the temperature distribution throughout the bed. The energy balance at the top of the bed includes terms characterizing the effects of entering and leaving hot gases, radiation and conduction into the bed, radiation to the bed from the hot gases burning overhead, and radiation to the bed from hot refractory in the furnace. This latter heat flux, characteristic of the incinerator design may be reflected in the sensitivity of combustible air pollution emission rates to arch height noted by Rose and Crabaugh[8]. However, inadequate experimental data have been obtained, and little detailed exploration of Mayers' work has been conducted to evaluate this hypothesis.

Other characteristics of interest in the refuse bed concern the flow characteristics of underfire air. The treatment of this subject is extremely complex in view of the wide diversity in the aerodynamic characteristics of refuse materials, and the changing bed structure as combustion proceeds and as modified by mechanical or manual stoking. The importance of undergrate air flow as regards suspension of particulate matter is discussed in Section VC.

Another area of interest in grate burning is the rate at which the carbon residue is consumed. Although a high carbon content in the residue may be innocuous from the standpoint of biological activity, it nevertheless presents the potential for fires at the residue disposal site and increases residue disposal requirements. Studies such as those by Howard[9] on refuse burning rate are useful starting points for this analysis. Considerable fundamental data are needed, however, on the burning of high-ash carbon-containing materials. In such cases, the combustion rate may shift from chemical reaction rate to diffusion control as the reaction proceeds. Also, heat loss rates may become important (especially near the end of the combustion process).

3. Overfire Burning

The grate burning processes described above introduce a constantly varying mixture of gases, vaporized tars, and particulate matter into the overfire volume of an incinerator. Unpublished data by Kaiser[10] indicate significant composition fluctuations in this flow. This is shown by analysis of accumulated gas samples withdrawn through a single water-cooled probe, where the average composition of gases shows the simultaneous presence of hydrocarbons and oxygen. Since, at the high temperatures characteristic of the probe location, these species could not co-exist, it is clear that the alternate eddys of fuel-rich and fuel-lean gases passed the sampling point.

Burnout of the combustible portion of this gas stream requires (but often does not receive) mixing at a molecular scale. Overall excess air levels, average gas temperatures, and mean gas residence times for conventional incinerators are consistent with this hypothesis. (This analysis is presented in some detail in Chapter V.)

Essenhigh[11,12] has suggested that the burnout of combustible species is controlled by chemical reaction. In view of the low Reynold's numbers (10^3 to 10^4) in the flues of most incinerators, turbulence levels are low. This fact, in combination with the analysis of reaction rates (Chapter V) suggests a combustion system dominated by turbulent diffusion. This is not to exclude Essenhigh's suggestions, but the above mentioned analysis, in combination with the flue gas stratification suggested by the data of Woodruff et al[13], do not lead one to believe that Essenhigh's suggestion is likely, though it cannot be said yet that it should be ruled out entirely.

4. Overfire Mixing Processes

The overfire volume in almost all combustion systems is in need of mixing. In many cases, the air stream entering with the fuel provides much of the mixing energy (as in gas burners, pulverized coal burners, etc.). In refuse incineration, however, little overfire turbulence is provided by the air and combustion gas flow from the refuse bed. As a result, the introduction of mixing energy in the form of overfire air jets is often desirable. This is particularly helpful in the region of the furnace where intense pyrolysis takes place, releasing substantial amounts of unburned combustible into the gas stream. This hot, fuel-rich gas is driven by buoyancy to the top of the chamber and out the flues into the secondary chamber. The relatively ineffective mixing which occurs in this flow is, in general, inadequate to assure burnout of soot, carbon monoxide, and hydrocarbons.

A number of authors have presented analyses and summaries of design equations addressed to augmenting the mixing processes in the overfire volume for real combustion systems. Often, due to the difficulties of mathematical description or experimental limitations, the analyses are focused most heavily on the behavior of free, round, isothermal jets. Although providing a basis for analysis, it must be recognized that flow in an incinerator differs considerably from this simplified model. In an incinerator the flow field of the jet is distorted by the cross-flow of gases rising from the grate and by combustion in an "inverted flame" formed by the air jet immersed in "fuel" provided by the refuse pyrolysis products.

The up-flow of momentum and "fuel" from the grate is a complex function of the undergrate air flow rate and the local combustion rate (Btu/hr sq ft). Clearly, the average value of this quantity varies along the grate, and, at any one point, varies moment-to-moment. Although little experimental or theoretical work has been carried out regarding jet behavior over refuse beds, considerable background exists on nonisothermal jets in cross-flow[14], and on cold jet behavior for conventional incinerator overfire air nozzle configurations[15]. A number of authors, however, have noted that mixing, even as reflected in the concentration decay in jets, does not necessarily indicate mixing at the molecular scale required for chemical reactions.

The majority of work conducted in the past on induced mixing in the overfire volume for incinerators has explored the use of air jets. In many cases, however, an incinerator already operates with a considerable excess of air and for modern water-wall boiler incineration systems, few constraints exist as to flue gas temperature. In these cases, the application of steam jets to induce turbulence, without significant dilution, may offer potential advantages. Alternatives often used in contemporary incinerators (baffles) are relatively ineffective in accomplishing mixing at the scale needed to assure complete combustion in minimum volumes.

Several texts[16, 17, 18] discuss, in varying detail, jet induced mixing. The reader having an interest in pursuing this subject is directed to these resources – there are also many others. However, the need and effectiveness of overfire jets in effecting complete and rapid burnout of combustible particulates and gases clearly have not been adequately explored in incinerator applications. The broad base of existing technology developed for steam locomotives and other coal-fired boiler applications, however, provides a strong analytical and empirical base for the introduction, with minimum technological risk, of advanced overfire mixing techniques.

Dynamic flow modeling techniques represent an equally applicable, though untried, tool for the study of the incineration systems. Historically, the high profit incentives of economical power generation have been required to justify the large research and engineering budgets required for the building and operations of these models and the analysis of the resulting data. The financial resources for comparable efforts with regard to municipal incineration have not been and probably will not be made available. As a consequence, future research efforts in this area will undoubtedly require support at the federal or state level.

5. Summary

In summary, much of the theoretical and empirical knowledge potentially useful in incineration system design has not been tapped by the incineration industry. It is clear, however, that improved incinerator operation, particularly as regards burnout of combustibles on the grate and in the flue gases, can result from incorporation of this existing art into future equipment designs. Also, these concepts appear to have direct applicability in the improvement of existing plants. Thus, while solid waste disposal by incineration will continue to represent a challenge to the designers, it should not be considered as a "black-art," depending only on past incineration experience for guidance in design innovation.

D. CRITERIA OF INCINERATOR PERFORMANCE

1. Introduction

The process of decision-making involves matching desired objectives with the known or forecast performance of alternatives. In many instances, the objectives are not formally stated. As long as the various facets of the objectives are compatible, this formalism may be unnecessary; but if they may be antagonistic, objective decision-making structures are called for. Three decision-making problems concerning municipal incineration are addressed in the body of this report: What modifications are necessary to upgrade the performance of existing plants? What are the relative merits of alternatives for new incinerator construction based on existing technology? What are the most promising new concepts now under development? In order to make these judgments, well understood and uniform criteria of incinerator performance are necessary.

The performance of an incinerator is of interest to many groups: consultants and designers, constructors, municipal governments, operators, and residents of the community in which it is to be built and operated. Each group's interests are different and, as a result, several differing opinions may exist as to what constitutes acceptable incinerator performance.

If an incinerator is to be evaluated objectively, it is essential to have performance criteria which cover all aspects of incineration and which are universal; that is, apply to all incinerators regardless of type, capacity, or age. Equally as important is the establishment of a well-defined procedure for determining the extent to which an incinerator meets these criteria. Such a rating system, however, is distinctly different from a statement of the criteria of performance as it reflects unique community needs rather than fundamental truths valid for all systems at all times. Formal rating systems, therefore, reflect the valid and necessary compromises of municipal decision-making.

Common to all incinerators are five performance criteria:

- Reliability
- Residue Quality
- Environmental Pollution
- Safety
- Net Cost

It is not the purpose of this study to establish the precise procedure for determining the performance of an incinerator using the above criteria. In order to be effective, they must be jointly agreed upon by the design and consulting engineers, interested professional societies, incinerator operators, and appropriate governmental regulatory agencies. One can, however, define each criterion and identify the important aspects to be considered in preparing a formal evaluation technique.

2. Reliability

Reliability is defined for the purposes of this report as the predictable operability of the mechanical plant and equipment. That is, if burning is scheduled five days a week for a four-week period, will the plant operate well mechanically over that time period? If the plant operates on a predictable basis, it would be judged to have good reliability; if many, unscheduled, unpredictable, mechanical or equipment failures occurred, the plant would be judged to have poor reliability. Scheduled downtime for routine or major maintenance does not indicate poor reliability; however, if such scheduled downtime was excessive, making the incinerator unavailable for burning for a significant fraction of the year, the plant would be considered unreliable, even though failure was predictable.

Because of different operating practices in incineration plants, it is difficult to establish guidelines for determining if downtime is excessive. In some instances, plants operate three shifts per day, seven days per week; while others operate only one shift per day, five days per week. Most plants have operating schedules between the two extremes. If a plant were scheduled for continuous operation, an operating factor of 85% would appear reasonable. This would mean that the daily burning rate would average 85% of the design daily burning rate over a period of one year. However, it does not mean that the plant would operate 310 days per year and be shut down 55 days per year; but rather, that when considering all events during the year, including when the plant was down or operating at above or below its design capacity, the burning rate averaged 85% of the design rate.

Plants operating only one shift per day, five days per week should have a much higher operating factor because maintenance can be done during the second or third shifts or on weekends. It would not be unreasonable to expect a 95% operating factor in this case.

The need for high reliability in incinerators is manyfold; the efficient operation of the refuse collection system, whether it is operated by the public works department or a private contractor, depends upon the operation of the incinerator. If the incinerator is down, the collection operations may have to be curtailed or halted, requiring collection schedules to be altered. In such cases, the problems at the incinerator have an immediate effect upon the residents of the community. If collection schedules are maintained, unburned refuse will have to be delivered directly to the residue disposal site, which is undesirable as it may result in air and water pollution, poor land utilization, and unsanitary conditions.

Storage capacity at the incinerator is generally quite limited because of the high cost of storage. Also, odor and vermin problems arise when storing refuse, particularly if it contains putrescibles. As a result, it is difficult to maintain pickup schedules, even on a minimal basis in critical areas, if the incinerator experiences an unscheduled outage for even a relatively short period of time (1-2 days).

The installed capacity of an incinerator plant must increase as its inherent reliability decreases, since the annual tonnage of refuse to be burned is independent of incinerator availability. For example, if the operating factor decreased from 85 to 75%, the daily burning rate would have to increase about 13% to burn at the same annual rate. A 13% increase in capacity would increase the initial cost of an incinerator approximately 10%.

If steam or power is to be produced as a by-product from the incinerator, the need for reliability can be greatly increased, particularly if these commodities are required on a firm basis. Also, the value of the steam or power is greatly increased if reliable supply to the customer can be assured. If steam or power cannot be provided on a firm basis and the customer cannot tolerate frequent interruptions, complete stand-by facilities will have to be maintained at the incinerator site or by the customer. If such backup facilities are required, the economic attractiveness of steam or power recovery is greatly reduced.

A more intangible benefit of reliable operation is uniformity of operation of the plant. Long periods of uninterrupted operation will result in lower operating costs because of better utilization of labor and utilities, lower maintenance costs because of better refractory life and equipment operations, and fewer pollution problems from poor residue quality, smoke, odors and the like.

Reliability can be achieved in many ways to varying degrees; however, in general, the greater the reliability of the system, the greater the cost of the system will be. Therefore, the need for reliability should be weighed against the cost of achieving it to make certain that the added cost is justifiable.

One method of achieving reliability is to provide duplicate units, each with the design capacity needed to match the communities' refuse generation rate. Such a system, with 100% spare or idle capacity, is much more reliable than a single unit, but will cost from 70-100% more. Countrywide, this is generally the approach taken: installation of twin units and operation an average of 50% of the time. Although this approach provides reliability, a heavy capital cost burden results.

With a decrease in reliability to burn at the needed incineration rate, three units totaling 150% of the refuse generation rate, could be provided. This system, with 50% spare capacity, is more reliable than a single unit but would require from 54-85% greater investment. With still a further decrease in reliability, two units, each rated at 50% of the refuse generation rate, could be provided. This system, with no spare capacity, is more reliable than a single unit but would cost 8-23% more.

There are obviously several other possible combinations of basic units, but the general rule is the same: as the reliability increases, the investment also increases. Multiple units will also increase operating costs. In particular, more operating labor will be required and, generally, maintenance costs will increase in relation to investment.

The trend in the chemical industry has been to larger single-unit plants. For example, in the production of ammonia, plant sizes have increased from 300 to

1500 tons per day over a period of about six years, primarily to reduce capital and operating costs in a very competitive industry. In general, the companies building such plants are aware of the risks involved and use enlarged maintenance staffs and improved maintenance programs to reduce the risk of downtime. Municipalities could profit from experience in such industries when appraising their incinerator capacity needs and in setting maintenance budgets.

A sound method of increasing reliability is to provide installed spare equipment where practical as a backup for sensitive or critical incinerator components. Examples include: pumps for the hydraulic system, or the flue gas conditioning system, and nozzles in various spray applications. In general, the provision of such spare equipment would add only 1-3% to the total investment for the incinerator.

An alternative to providing complete spare equipment would be to install two pieces of equipment, each designed at 50-60% of the required capacity. In such a system, partial operation would be possible even with the failure of a critical piece of equipment. The cost of providing such equipment would add 1-3% to the investment exclusive of a traveling bridge crane which would cost about $100,000 in the size range where duplicate cranes may be considered (above 400 TPD).

A third method of increasing reliability is to provide means for bypassing equipment; for example, it is standard practice to provide a control valve bypass. In an incinerator, bypasses may be provided for pumps, if it is possible to use water directly from the city water main, for air pollution control devices, and for forced draft air fans. The cost of providing bypass features in an incinerator is small, probably not amounting to more than 1% of the investment. However, bypass systems are intended to serve an emergency purpose, not to avoid maintenance or to ease operation. In far too many plants, the improper use of bypass systems degrades plant performance and increases maintenance costs.

A fourth method of increasing reliability is to maintain an adequate inventory of spare parts to facilitate repairs. It is particularly important to have spare parts on hand for those pieces which are "specials" and will require long delivery times. There is a lesser need for standard spare parts such as motors, since these can usually be obtained locally for immediate delivery. An adequate spare parts inventory will add from 1-3% to the initial investment.

Reliability can also be improved with preventative maintenance and continuous long-term operation of the incinerator. Preventative maintenance would include a rigorous periodic inspection program, the overhaul of equipment prior to failure, and the execution of a well-planned, well-organized normal maintenance program. It is difficult to argue that such a program would increase the net annual operating cost of incineration. On the contrary, it has been shown repeatedly that aggressive maintenance actually decreases costs.

Continuous 24-hour operation improves reliability because of its favorable impact on the performance of materials and equipment. Refractory materials perform better when operating at uniform temperatures as opposed to thermal cycling caused by repeated startups and shutdowns. Since refractory repairs represent almost half of most incinerator maintenance budgets, longer refractory life also improves plant operating economics. Corrosion will be reduced by eliminating condensation during shutdown.

3. Residue Quality

The principal objectives of the incineration process are to reduce refuse in both weight and volume to produce an innocuous residue. It is extremely difficult to establish firm criteria for determining how well these goals are achieved because of the variable nature of municipal refuse and the severe problems of sampling and analysis of residues. There are, however, qualitative and quantitative tests which can be used in conjunction with a knowledge of the composition of the refuse to be burned to establish the effectiveness of the incinerator in producing an acceptable residue ash.

Acceptable residue ash can only be achieved by prudent operation. This requires teamwork on the part of the entire staff. The superintendent must set plant priorities to assure high-quality ash rather than demanding high tonnage burning rates at any cost. The crane operator must mix different materials (grass clippings, chemical wastes, dry refuse, paper, garbage, ashes, etc.) in the pit to provide a relatively homogeneous feed stream (from a combustion standpoint) to the furnace. The furnace operator must constantly check and adjust his overfire and underfire air ratio, the degree of agitation of the fire, the temperature of the furnace, and the residence time of the refuse flowing through the furnace.

Such operation requires constant attention and may reduce throughput when the refuse is difficult to burn. However, it has been demonstrated in many incinerators in operation at the present time that high-quality residue ash can be consistently obtained if good operating practices are followed.

The following paragraphs discuss the various aspects of residue quality. Their relative importance must be determined in the context of local economics, transportation problems, residue disposal site hydrology, future use of land, environmental restraints, etc.

a. Weight Reduction

The determination of the reduction in weight is relatively straightforward, involving weighing the refuse fed to the incinerator and the residue discharged from it over a period of time sufficiently long to eliminate inaccuracies caused by holdups in the system. Care should be taken to make sure that fly ash is included in the weight balance and that water used for ash quenching is not. It should also be recognized that wastes such as mattresses, large appliances and construction debris not fed through the incinerator should, perhaps, be included in the analysis. Including these wastes, on a proportional basis, reveals the true role of the incineration system in weight reduction. Typically, weight reductions of 65% to 90% will take place during incineration depending upon the composition of the refuse to be burned. Complete burnout assures maximum weight reduction.

b. Volume Reduction

The reduction in volume is more difficult to establish accurately than weight reduction. For repeatability and comparability, it is important to clearly establish the basis for the measurement, since the reduction in volume can vary greatly depending on where in the system the volume of refuse and the residue ash is measured.

The volume of refuse can be measured as it is collected from the household at which point its density is quite low; after compaction in the packer trucks when its density is at its highest or in the pit when its density averages 375 pounds per cubic yard. The density also depends upon the composition of the refuse, its moisture content and the way it is handled and stored in the pit. Densities in the pit from 250 to 580 pounds per cubic yard have been recorded during recent studies.

The volume of the residue will also vary depending on where the density is measured and how the sample is collected. Measurements may be taken before it leaves the grate, either before or after it is quenched, or before or after grate siftings and fly ash have been added. Also, bulky unburned materials may or may not be included. Alternatively, measurements may not be made until the material is discharged on the dump and compacted with a bulldozer. Densities from 900 to 1500 pounds per cubic yard have been recorded for residue ash leaving the grate. Volume reductions from 50% to 90% are believed to be typical for municipal incinerators on the basis of refuse volume measurements made in the pit and residue ash leaving the grate. Increased reductions in volume can be accomplished with better agitation, complete burnout, and high-temperature operation to assure that all glass is shattered in the furnace. In several incineration concepts now under development, melting of the residue promises volume reductions approaching 97%.

c. Composition of the Residue

The composition of the residue is of interest from several points of view:

- As a diagnostic aid in detecting operational problems,

- To determine completeness of combustion;
- To identify potential water pollutants.

The chemical analysis of a completely combusted residue is wholly determined by the composition of the refuse and not by operational practices. Tests for residue quality should, then, principally be designed to permit the operator to establish the completeness of combustion and the nature of the unburned material rather than to provide detailed chemical composition data. When operational problems such as slagging are encountered or when slagging of the residue is part of the process, however, such detailed analyses may be necessary. Establishing the completeness of combustion of the residue is perhaps the easiest and most useful analysis which can be made on the residue. It will indicate if maximum weight and volume reduction are being achieved and if the residue is free of noxious materials. (Metallic residues, heated in the presence of air, will undergo a weight gain, thus, to some measure, distorting the results.)

A well-operated, modern incinerator should be achieving approximately 97% burnout. However, to attain such performance, control of temperature and overfire and underfire air rates, increased agitation during burning, and increased residence time in the furnace must be maintained.

As the residue will most likely be disposed of at a dump site on marginal land, the principal objectives of more exhaustive analysis would be to suggest the potential for the residue to cause ground water pollution, to support vermin, and to create odors.

d. Water Soluble Fraction

The water solubility of the residue is of interest primarily to evaluate potential ground water pollution, as this fraction will, to some extent, be leached from the ash over long periods of time and may contaminate ground water. Such leaching may or may not be harmful depending upon the materials which are dissolved and the rate of solution. In general, the amount of water-soluble materials in the ash will be quite small and will reflect the composition of the refuse burned and the operating practices of the incinerator. The extent to which ground water contamination occurs or is important is primarily dependent upon the method of fill operation and the local rainfall, drainage patterns, and geology, which vary widely, each fill site requiring detailed evaluation.

e. Organic Soluble Fraction

The organic soluble fraction of the residue indicates the extent to which proteins, carbohydrates, and fats are present. These materials are of interest because they will support undesirable forms of life, such as insects, rodents, and bacteria and may putrefy. If the level of putrescibles is found to be over 1% of the residue ash, the incinerator is not being operated properly, as all organic materials are combustible. Increased residence time in the furnace, high temperatures, good agitation, and proper combustion air distribution will reduce putrescibles to an acceptable level in the grate residue. Siftings, however, may require reinjection to assure adequate burnout.

f. Sterility

The biological population of the residue is a measure of its ability to transmit disease either directly to human beings or to insect or rodent vectors which may then transmit it to human beings. If putrescibles are present in the residue, it is likely that viable organisms will be found. In the absence of putrescibles, sterility is probable. The presence of living organisms may be established by incubating cultures of the ash. If organisms are present, they should be classified to establish what fraction is pathogenic. Fungi or bacteria indicate that burnout of the ash is not complete. (Ash recovered from the residue quench water is not suitable for such tests, as most quench water sumps support a vigorous microbial population.)

g. Physical Characteristics of the Residue

The physical characteristics of the residue (the particle shape and size distribution and bulk density) are of interest in establishing its value for fill. If the material is free of large pieces of metal and glass and is relatively granular, it may be ideally suited to be used as ballast material or as fill. Under these circumstances, the ash may actually have a value, particularly if users can be found relatively close to the incinerator.

Even though the material may not be ideal as a fill, if the glass and cans are crushed, the material will be well suited for the reclaim of marginal land. Residue processed in this manner will result in land that can be reclaimed rapidly and used to the benefit of the community. Poor quality residue which contains much unbroken glass, whole cans, and other bulky objects, and a significant amount of unburned material, will occupy more land volume initially and require a much longer "resting" time before the fill is sufficiently consolidated to permit construction. The quality of the residue depends somewhat on the composition of the material which is burned but is also greatly dependent upon the method of operation of the incinerator. Good agitation and high temperatures will be beneficial in producing an ash of good quality.

4. Environmental Pollution

An incinerator is probably of greatest concern to a municipality because of the fear of the pollution of the contiguous environment. The principal concerns are air and water pollution. However, an incinerator can also create undesirable noise and cause the surrounding area to be unattractive because of paper and other forms of trash which almost invariably disfigure an incinerator site.

a. Air Pollution

The most noticeable forms of air pollution are fly ash, smoke, odors (from the stack as well as other areas), noxious gases, and dust. All emanate from an incinerator at times.

(1) Composition of the Flue Gases. If combustion of the volatile fraction of the refuse is complete, the composition of the flue gas will be principally nitrogen, oxygen, and carbon dioxide. There will be small amounts of sulfur oxides, nitrogen oxides, and traces of mineral acids (principally hydrochloric acid, which will result from the combustion of halogenated plastics, particularly polyvinyl chloride). Normally, the concentration of sulfur oxides, nitrogen oxides, and mineral acids will be low enough so that they will not cause significant air pollution. It is doubtful if it is necessary to treat flue gases to remove these materials.

If combustion of the volatiles is not complete, the flue gases will contain significant amounts of carbon monoxide and other uncombusted or partly combusted organic materials. The first indication of the presence of these materials will be the appearance of black smoke from the incinerator stack, which may be followed by the detection of objectionable odors.

The presence of such unburned or partially burned materials is unnecessary and is caused by the poor operation of the incinerator. Their emissions should be controlled by the proper operation of the incinerator rather than the installation of control devices. Complete combustion can be assured by operating the incinerator at the proper temperatures (from 1400°F-1800°); by providing sufficient air for combustion; by providing sufficient residence time for the combustion process to occur; and by inducing (either by gas passage design or overfire air jets) sufficient turbulence in the combustion space to mix the combustible gases and aerosols with the necessary air.

Such residence time and some mixing is usually provided for by ducting the flue gases to a secondary combustion chamber. Although it is not essential that such a chamber be provided, it is necessary to provide sufficient volume and vigorous induced mixing in the furnace to assure that the combustion process is completed. Few single-chamber incinerators meet this need.

(2) Particulate Matter. Particulate matter (characterized by flue gas weight loading), generally referred to as fly ash, is generated in the combustion process and must be removed from the effluent gases. The amount of particulate matter which is generated is somewhat dependent upon the design and operation of the incinerator. If the combustion process is not complete, a sooty fly ash will result. The best way to control emissions of this type is to assure that the incinerator is operated at temperatures sufficiently high to assure complete combustion of these materials.

Studies have been made which indicate that there is a correlation between the amount of fly ash entrained in the effluent gases and the distribution and amount of overfire and underfire air and the type of grate employed. Proper operation will assure that large amounts of fly ash do not become entrained in the gas stream because of improper air distribution.

There will be, however, no matter how carefully the incinerator is operated, particulate matter entrained in the effluent gases. The extent to which the particulate matter is removed from the gases depends upon the type of emission control equipment which is used and the way it is operated and maintained. If abnormal amounts of particulate are being emitted, it may be that the incinerator is being operated improperly. This happens, for example, when combustion is quenched by large amounts of air admitted to the incinerator in an uncontrolled manner, such as occurs in batch feed incinerators. Also, the emission control equipment may not be operating properly. Problems which could occur in the operation of APC equipment include: the plugging of spray nozzles caused by either water hardness or large amounts of solid in recirculated liquid streams, the plugging of cyclones caused by sticky particulate or condensation, and failures in the electrical systems of a precipitator.

In a properly designed and operated incinerator, equipped with appropriate air pollution control equipment, the standards established by most states and the Federal government can be met.

(3) Smoke. Smoke (characterized by flue gas opacity) may either be ash material, which is completely burned but is very finely divided, or an unburned or partly burned combustible material (tar aerosol). If the smoke is an ash material, control requires the use of very high-efficiency emission control equipment. It may be lessened to some extent through improved operation by adjusting the air distribution in the primary furnace.

If the smoke is combustible, it can best be controlled by improved combustion efficiency. Longer residence time, better air distribution, gas mixing, and high operating temperatures will eliminate such pollution.

(4) Odor. In addition to odors which emanate from the stack because of poor combustion, there are odors in the pit and in the residue handling area, particularly if water is used for quenching and sluicing the grate siftings. Odors may also emanate from the dump.

The odors from the stack can be best controlled by assuring complete combustion of the gases. This is done by proper air distribution, elevated temperatures, and proper residence time at these temperatures. Such control is much more effective and less costly than using equipment, such as scrubbers, for odor removal.

Odors in the pit can be controlled by using masking deodorants, minimizing the time the refuse is stored in the pit, planning the withdrawal of material from the pit, and periodic cleaning. The deodorants can be applied by using a spray network permanently installed in the pit. However, such a system should only be used in conjunction with a good cleaning program. The crane operator should establish a systematic plan for withdrawing refuse from the pit to insure that no refuse stays in the pit too long (as by working from one end of the pit to the other). Cleaning should be done once a week by washing the pit down. This can be done without completely emptying the pit by scheduling the washing of only portions of the pit at one time.

Odors in water systems used for quenching the ash and sluicing the grate siftings can only be accomplished by a very active cleaning program which involves changing the water at least once a week and through washing of the equipment. Wet ash handling systems are, at best, messy and difficult to keep clean, particularly if burnout is not complete.

(5) Dust. Dust is emitted from the pit area when trucks unload and when the crane is operating, from the residue handling area, and from the fly ash handling area. Dust raised during unloading can be controlled by enclosing the tipping area. Also, sprays can be used to moisten the refuse in the pit to minimize dust during the feeding. Dust in the ash handling area can be controlled by using sprays to moisten the ash and using closed transfer and hopper systems to minimize dust leakage. Some systems of these types are currently being used and have been very effective.

b. Water Pollution

Water is generally used and rejected from most incinerators. It is used to wash down the pit and ash handling systems, to quench hot residue and fly ash, for dust control, and for gas quenching and scrubbing. Water which is rejected from the incinerator will most likely be polluted in one way or another.

The wash water used throughout the plant and the water which drains from the pit and ash handling systems will probably have a high BOD and COD and contain suspended and dissolved solids, both organic and inorganic. Since the quantity of this water will be relatively small, it may be discharged into the sanitary sewer or septic system. It should not be discharged to storm drains or streams without treatment.

The water rejected from quenching and scrubbing systems may be quite large in quantity and very hot. It will also be high in suspended and dissolved solids and have a low pH. The solids will be both organic and inorganic. The BOD and COD may also be higher than desirable. In some designs, the scrubbing water is settled to remove suspended solids and recycled; in others, it is discharged after use. Recycling has often proved to be troublesome because of the plugging of lines and spray nozzles with solids and scale.

Water which is discharged should be sent to a well-designed settling pond to remove solids and permit cooling. If it is to be discharged to a stream, secondary treatment consisting of pH adjustment and possibly digestion to reduce BOD and COD may be required. The rate of discharge may have to be controlled to prevent the buildup of soluble solids in the stream.

If water is used only for quenching, systems could be designed to obtain 100% evaporation and thereby eliminate any disposal problem. Wet scrubbers which permit recirculation without plugging are also highly desirable.

c. Noise Pollution

The noise created by the operation of an incinerator can be a disagreeable nuisance. Many large trucks are constantly delivering and removing material from the plant. Also, large fans, pumps and other equipment often operate 24 hours per day. There are a number of approaches to control truck noise, including use of proper exhaust mufflers and enforcement of low-noise operating procedures. Also, the noise from the equipment in an incinerator can be controlled by use of enclosures, or silencers, where appropriate (particularly on the large fans).

d. Aesthetics

(1) Plant Appearance. Much can be done to improve the appearance of an incinerator by maintaining the landscape and buildings and keeping the immediate area free of litter and debris. Roads, sidewalks and work areas should be periodically washed and litter collected on a regular basis. Although work in this area does little to improve the operation of an incinerator, it can have a great impact on the attitude of the community.

(2) Plumes Due to Condensation of Water Vapor. Water vapor is always present in the effluent gases, depending upon the refuse composition and the flue gas conditioning or air pollution control (APC) system design. If sprays are used to quench flue gases to 600°F, only a small amount of water is used and a water vapor plume would probably not appear unless the weather was very cold or damp. However, if a wet scrubber is used for particulate control, the effluent gases may be saturated; causing a water plume under most atmospheric conditions. Such a plume, if objectionable, can be eliminated by reheating the gases, though usually at a prohibitive cost.

5. Safety

A modern incinerator has a great many potentially hazardous conditions: the crane operator and charging floor men work in a dusty environment near a pit, with the crane operating overhead; the operators are exposed to hot surfaces and flying projectiles from the furnace; the ash handlers work in a dusty area and may be exposed to hot materials; there is a fire and explosion hazard in the furnace; and rotating or reciprocating equipment is operating in all parts of the plant.

A criterion for evaluating plant safety is the number of man-hours lost per year to accidents. Unfortunately, consolidated data were not found for a statistical reference point against which to compare plant safety records. Equally as important as a "good" record, however, is the potential for accidents in the plant. The measure of this quality is of needs subjective, but it reflects the commitment of the plant staff to the principles of safety. Hard hats not worn, protective alarms disconnected, furnace doors left open and unattended, storage of flammable liquids near the combustion chamber, unrepaired guards on equipment drivers – these are the signs of failure in commitment to safety.

The operators should have and use proper safety equipment, particularly safety hats, shoes, and glasses. Dust masks may be appropriate in dusty areas. The furnace operators should wear full face masks, particularly if they are expected to stand before an open furnace. The crane operator may need an air-conditioned cab and must have egress from the crane at both ends of the pit should there be a pit fire.

The pit area should be provided with sprays and hoses to combat fires. Adequate ventilation should be provided in the pit area to prevent the buildup of dust. Ventilation should also be provided in the ash handling areas for dust control.

A regular cleanup schedule in the plant should be planned and adequate eating and shower facilities provided. Personal hygiene should be stressed to the men. Incinerators should employ the same safety philosophy as industrial plants, as the hazards at an incinerator are equal to or greater than those found in industry.

6. Net Cost of Incineration*

The net cost of incineration is defined as the annual cost of operating an incinerator, taking into account all expenditures (including indirect costs such as overhead and debt retirement) and all income (including revenue derived from the sale of steam, power, or scrap). The cost can be expressed in two ways: either as a total annual net cost or as a net unit cost ($/ton of refuse incinerated). In either case, it is necessary to know the annual tonnage of refuse incinerated as well as the total annual cost if the cost-effectiveness of the incinerator is to be evaluated.

It is extremely difficult to establish general cost guidelines for incinerators because of great variability in the design and operating practices which influence costs. The initial cost of an incinerator will vary greatly depending upon site location (particularly if soil conditions are poor), building design, pit storage capacity, and the type of air pollution control system used. It would not be unreasonable for two incinerators to vary in cost by 100% although each was designed for the same capacity.

The reported total annual and unit operating costs will also vary greatly depending upon the particular incinerator under study. The annual capacity and operating schedule have as large an impact on costs as does the basic design of the incinerator. In addition, there are no uniformly used formats to establish operating costs which take into account all direct and indirect costs incurred by the municipality operating an incinerator.

a. Capacity

It is important to establish the annual tonnage of refuse incinerated based on actual records of weight of material delivered to the storage pit. If the annual throughput is lower than the design capacity of the incinerator, lower costs could be realized by increasing the annual burning rate since some costs, such as indirect overhead, amortization, and insurance, are fixed regardless of annual throughput, and others, such as operating labor, maintenance, and labor overhead, do not increase in proportion to the annual throughput.

If the throughput is controlled by the demand of the municipality, it may be possible to increase annual tonnage by burning the refuse of another municipality, which would provide additional income as well as lowering the unit cost of incineration. If the burning rate is controlled by restrictive operating schedules, the unit cost of incineration will be increased by operating more hours per year, which may mean multishift operation as many as seven days per week. Benefits such as reduced maintenance, better residue, and reduced air pollution may result, however.

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*See also Chapter VII.

However, ton/day is not a valid measure of incinerator capacity. In fact, an incinerator is a heat disposal system; not a weight or volume disposal system. If refuse heat content could be as easily measured as weight, therefore, a more uniform and technically correct scale would be available.

b. Initial Investment

The initial investment is important because it represents indebtedness to the community and an operating cost (debt retirement). Invariably during the design and construction of an incinerator, there is tremendous pressure to reduce its first cost. This is done by architectural changes, the elimination of equipment or equipment systems (such as the APC system) and by the dogged acceptance of low bids with little attention paid to quality or reputation. Although in many cases cost reductions are necessary and justified, all too frequently cost reductions are made without full understanding of the effects of the reduction on plant performance.

In optimizing the design and cost of an incinerator, a total cost format, taking into account both the original cost of the incinerator and the operating cost for the life of the plant (15-20 years), should be used. This method of analysis will show that, in many cases, additional money spent during the design of the incinerator will be saved many times over by reducing operating costs, even when using present worth or discounted cash flow evaluation criteria. Operating cost reductions will be realized through a reduction in costly additions to plant after it has been built, increased reliability, and reduced maintenance costs. Another advantage of installing an optimally designed incinerator is that it will meet the pollution regulations existing at the time of construction or anticipated in the near future, thereby assuring continued operation with a minimum number of complaints.

c. Land and Land Improvement Costs

The cost of land and any improvements to the land should be included in the original cost of the incinerator. If the land is already owned by the city, a charge should be assessed to the incinerator which represents a fair market value for the land. The loss in tax revenue for the land should be charged as an annual operating expense as well as debt retirement if the land was purchased. Although these costs may not represent actual out-of-pocket expenses, they are real costs in operating the incinerator and if an entrepreneur were to own and operate an incinerator for a municipality on a contract basis, these costs would have to be included as a cost of business. The cost of land and land improvements are almost independent of capacity but depend to a major extent upon the plant site and soil conditions at the site.

d. Utilities

The consumption of utilities such as power and water varies greatly depending upon the design of the incinerator.

Power requirements may be very small if only a natural draft stack is used for the movement of all gases (both combustion air and effluent gases). On the other hand, power requirements may be quite high if forced draft and induced draft fans are used or if high-pressure drop water scrubbing is used. Water requirements will vary depending on the type of gas quenching and scrubbing systems and depending on whether or not water is recirculated or used on a once-through basis.

The cost of utilities is significant and should be charged to the incinerator whether they are provided by a public utility or by the municipality. In addition to power and water, other costs such as steam, compressed air, and sewer taxes should be charged to the incinerator, as they represent real costs of operation.

e. Operating Supplies

Items such as greases and lubricants, instrument charts, uniforms, gloves, gasoline and safety equipment are included in this category. The cost of supplies should be $0.25 to $0.50 per ton of refuse incinerated.

f. Operating Labor

The operating labor force includes all personnel employed at the incinerator complex directly associated with the operation of the plant, such as the crane operator, firing floor operator, ash handlers, and cleanup personnel. Also included are the weigh clerk, foremen, and superintendent. Excluded are the maintenance force and personnel such as payroll clerks and other overhead personnel who are normally located elsewhere.

The number of operating personnel (excluding the maintenance force) is relatively constant regardless of the type of incinerator design. Usually five or six operators will be required per shift with two additional personnel (the superintendent and the weigh clerk) required for the day shift. If more personnel are normally used, the need for them should be carefully examined.

g. Maintenance

Maintenance costs include the maintenance labor force, both craftsmen and direct supervisory personnel, as well as all repair and replacement materials and all costs for any maintenance work done on a contract basis (such as crane and instrument repairs).

The cost of maintenance is a function of investment and the annual cost of maintenance should approximate 2½% to 4% of the total cost of the plant. In most plants, a portion of the maintenance is accomplished by the operating crews and not identified on plant records as a maintenance expense. In general, it is such accounting differences (rather than true annual cost differences) which justify the range in percentages. If maintenance costs are high, the operating procedures for the plant should be reviewed, as they can seriously influence maintenance costs. Also, the age and design of the major equipment should be reviewed to determine if replacements should be made. The design of the incinerator should be examined to determine if there are basic design flaws which will have to be remedied before maintenance costs can be reduced.

All major maintenance expenditures should be examined to make certain that the money is being spent in a cost-effective manner. If chronic maintenance problems are identified, to overcome such problems consideration should be given to redesign or complete replacement of the equipment involved.

h. Overhead Costs

Overhead costs are divided into two categories: labor overhead, which includes social security, medical benefits, workingman's compensation, vacations and all other fringe benefit costs associated with the operating and maintenance labor forces, and indirect overhead, which includes accounting, purchasing, general supervision and other administrative costs which for a municipality will probably be provided at a central location such as the city offices. The indirect overhead costs will probably be prorated on a formula basis established by each community. In any case, these costs should be recognized as a real cost and be included when considering the actual cost of operating the incinerator.

Labor overhead costs are directly related to the number of personnel employed and will approximate 30-50% of the direct labor cost. The exact cost will vary depending upon the fringe benefits package provided by each community.

Indirect overhead will vary greatly if the incinerator is operated by a municipality since costs will undoubtedly be allocated to each department on a formula basis. If the incinerator is privately owned, indirect overhead costs will approximate 50-70% of the cost of direct operating labor and supervision.

i. Insurance (and Taxes, if applicable)

Insurance includes such items as fire insurance, liability insurance and other insurance policies which are maintained for the incinerator. If the incinerator is privately owned, ad valorem taxes and property taxes will also have to be paid. A municipality will not have to pay such taxes but may wish to consider the loss of income which results because the incinerator is publicly owned.

Insurance will approximate 3/4 to 1% of the total plant cost per year, and property taxes (if paid) will be about the same as insurance. Income taxes, in the case of privately owned incinerators, range from 50-60% of gross profits.

j. Amortization

If the incinerator is publicly owned, payment of the principal and interest to retire the indebtedness of the municipality incurred as a result of building the incinerator must be included as an operating cost. If the incinerator is privately owned, depreciation, capital charges for working capital and a profit will be included instead of amortization.

The annual charges for amortization will depend upon the debt retirement schedule and the interest to be paid for the land but will approximate 9% of the fixed capital investment based on a twenty-year bond issue. If the incinerator is privately held, the total annual capital charges for depreciation, interest, and pretax profit will approximate 20% of the fixed capital investment. Public utility ownership results in annual capital charges of 13-15%.

k. Credits*

An incinerator has the capability of generating income from several sources: the sale of power or steam, the sale of scrap or residue ash (for fill), the burning of refuse from neighboring communities, commercial establishments or industry on a contract basis, or by increasing the value of marginal land by reclaim using residue ash.

The amount of income will be greatest if utilities are generated for sale and refuse is burned on a contract basis. The sale of residue ash or scrap will probably not generate substantial income.

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*See also Appendix F.

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APPENDIX I

PRESENT MUNICIPAL INCINERATORS IN THE UNITED STATES

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PRESENT MUNICIPAL INCINERATORS IN THE UNITED STATES

A. INTRODUCTION

The objective of this portion of the report is to indicate the current design trends and operating practices in existing U.S. incinerators. Included within the scope of this task is a description of the present incinerator inventory. Also, the results of a questionnaire solicitation (Appendix D) are reported. This questionnaire sought both design and operating data from the existing incinerator inventory.

Within the operating lifetime of many active incinerator plants, U.S. incineration technology has advanced from the early hand-stoked hearth units to contemporary mechanically stoked waterwall boilers. This advancement has been ponderously slow and unstructured. A typical municipality installing an incinerator is understandably conservative as regards to design decisions. For many communities there is only one incinerator; it must work! Also, the investment is large and technological risk is not always clearly justified by reduced operating costs or other less tangible enhanced performance criteria.

In some instances, the resulting incinerators have been aesthetically displeasing, poorly designed, inadequately maintained, and indifferently operated. In other plants, preconceived architectural features have demanded awkward layouts or have placed space limitations upon the process equipment which required unfavorable performance compromises. Many plants have been built to specification which fail to carefully define the functional interfaces between the air-handling systems, grates, air pollution control systems, induced draft fans, and other interrelated incinerator subsystems. These problems in the design and operation of incinerator systems reflect, in part, the difficulties of the inherently political, often technically untrained municipal officials in making technical decisions.

It would be remiss not to mention the large number of well-designed, well-run plants throughout the country. In more cases than not, however, these plants are found in unusually enlightened communities and, almost without fail, are operated under the direction of highly motivated and dedicated plant superintendents. Often, it is the determination of these individuals rather than advanced designs which account for the level of performance.

An important cause of past difficulties has been the inadequate and ineffective exchange of information and ideas between the municipality and the technical community. In recent years, however, communications between the municipalities, consulting engineering firms, contractors, and vendors have improved. Bridges to the academic community and to research firms are slowly forming. This is due, in part, to the activities of professional societies such as the Incinerator Division of ASME and the Institute for Solid Wastes in the APWA. Also, many of the cities, recognizing the contributions of modern technology, have improved and augmented the technological resources within the city government itself, and are reaching out to the nation's universities and research firms for help in seeking creative, modern solutions to modern problems.

B. INCINERATOR INVENTORY AND DESIGN TRENDS

In the paragraphs which follow, a compilation of data on existing incineration systems is presented. This inventory was developed through a review of published sources (see Volume III – Bibliography), through personal contacts with professionals active in the field and by use of a questionnaire (Appendix D). These data are subsequently presented in graphical and tabular form to illustrate the direction of design trends for contemporary incineration systems as reflected in plant construction.

The introduction of Federal assistance through demonstration grants and the increasing urgency of the solid waste disposal problem has greatly accelerated the pace of design innovation. As a result, a number of concepts new to the United States (especially the use of waterwall boilers), are being introduced at a rapid pace. However, the long-range growth potential of these concepts cannot yet be established. In time, the unique characteristics of the U.S. economy and refuse will undoubtedly have an influence on the direction and rate of implementation of these new concepts. In light of the results of the technology review presented in the Techno-Economic Analysis (Chapter VII), it is clear that no impelling technical or economic miracles appear on the horizon. The incineration concepts of the future now exist; although engineering research is badly needed to provide sound and reliable design principles to improve the technology and to develop several "advanced" concepts offering features which would be helpful to particular municipalities.

1. Incinerator Inventory

Table I-1 which follows was developed by compilation of data from a large number of sources. Unfortunately, a number of serious problems in basic definitions exist throughout the incinerator industry, particularly concerning the meaning of "scrubber" and "wet baffles" and aspects of the combustion air system. Such problems compound the difficulty in producing an accurate compilation without personal contact with each and every incinerator described which was, of course, not possible.

TABLE I–1

INCINERATOR INVENTORY

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
1.	Philadelphia, Pa. (Harrowgate) (see line 165)	1922	Rebuilt '54	300	2	150	Batch/Stationary		None	Steam
2.	Minneapolis, Minn. (see line 46)	1924		150	1	150	Batch/Stationary		None	
3.	Hamilton Township, N. J.	1925	Add'ns '42,'45	99	3	33	Hearth Type/Stationary		WW	
4.	Allentown, Pa. (see lines 23, 145)	1925		90	1	90	Conv. Boiler/Stationary		None	
5.	Laredo, Texas	1925	Closed '66	24	1	24	Hearth		None	
6.	Pennsauken, N. J. (see line 139)	1926	Rebuilt '53	60	1	60	Fixed Hearth/Circular		None	
7.	Hackensack, N. J.	1927	Closed	100	1	100	Stationary Grates		WW	
8.	Buffalo, N. Y.	1927	Close '70	400	5	80	Stationary (Manual)		None	
9.	Tonawanda, N. Y. (Town) (see lines 90, 112)	1928		70	1	70	Batch Hearth/Manually Stoked			
10.	Middletown, N. Y.	1929	Closed '68	50	1	50	Stationary Grate		None	
11.	New Rochelle, N. Y.	1929	Closed '46	150	3	50	Hearth Type		None	
12.	Perth Amboy, N. J. (see line 172)	1929		50	1	50	Stationary		None	
13.	Oshkosh, Wisc.	1929		100	1	100	Hearth/Hand Stoked		None	
14.	Racine, Wisc. (see lines 76, 169, 233)	1929		120	2	60	Hearth		None	
15.	Red Bank, N. J. (see line 173)	1930		60	1	60	Hearth Type		None	
16.	Spring Lake, N. J.	1930		30	2	15	Stationary		None	
17.	Milwaukee, Wis. (Erie St.)	1930		225	3	75	Rect. Cell/Pinhole Grates	Nat.	None	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
18.	Atlantic City, N. J.	1931	Closed '68	96	3	32	Stationary		None	
19.	Elmira, N. Y.	1931	Closed '68	100	2	50	Stationary		None	
20.	Princeton, N. J. (see line 157)	1932		60	2	30	Circular		None	
21.	Schenectady, N. Y.	1932	Closed '67	240	3	80	Stationary/Hand Stoked		None	
22.	Portland, Ore.	1932	Closed	75	3	25	Stationary		None	
23.	Allentown, Pa. (see lines 4, 145)	1932	Add'n	180	1	90	Stationary/Conv. Boiler		None	
24.	Washington, D. C. (Georgetown)	1932		170	2	85	Stationary Grate		WW	
25.	Washington, D. C. (O Street)	1932		425	5	85	Stationary Grate		None	
26.	Baltimore, Md.	1933		600	4	150	Rocking Grate		WW	
27.	Cincinnati, Ohio	1933		200	2	100	Rocking		None	
28.	Cincinnati, Ohio (Red Bank)	1933		200	2	100	Rocking		S, Ping Pong Ball Scrubber	
29.	Shreveport, La. (see lines 250*, 99)	1934	Closed	150	1	150	Stationary		None	
30.	New York, N. Y. (Bronx)	1934	Closed	750	5	150	Stationary Dump Grate	U,O	D	Salvage
31.	New York, N. Y. (W 215th)	1934		750	5	150	Rect. Cell/Stat. Dump Grate	U,O	D	Salvage
32.	Middletown, Conn.	1936	Closed	60	1	60	Hearth		None	
33.	Cleveland, Ohio	1936	Closed	900	3	300	Stationary		D	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Furnaces Mech. Draft	APC Equipment	By-Products
34.	New York, N. Y. (Flushing)	1937	Closed	300	3	100	Stationary Dump Grates		None	
35.	Glen Cove, N. Y.	1937	Close '69	100	2	50	Stationary Grates		None	
36.	Manchester, N. H.	1937		125			Rect. Cell/Flat Dump. Gr.	U,O,I,D	None	
37.	Greenwich, Conn. (see line 284)	1938		150 250	1	150	Batch-Rect./Contin.	Nat.	D,S	
38.	Cambridge, Mass.	1938		150	3	50	Cell/Horiz./Hand Stoked	Nat.	None	
39.	Detroit, Mich. (St. Jean) (see line 212)	1938	Rebuilt '57	350	2	175	Stationary		None	
40.	Detroit, Mich. (NW) (see line 211)	1938	Rebuilt '57	450	3	150	Stationary		D	
41.	Detroit, Mich. (Cen.) (see line 59, 228)	1938		350	2	175	Stationary		None	
42.	Detroit, Mich. (24th St.) (see line 290)	1938	Rebuilt '63	500	2	250	Batch/Stationary		D	
43.	Tonawanda, N. Y, (see line 229	1938	Closed	50	1	50	Basket Type Furnace		None	
44.	Lower Merion, Pa. (see lines 94, 362)	1938	Close '69	100	2	50	Stationary	Yes	None	
45.	Athens, Ga.	1939		48	1	48	Cylindrical		None	
46.	Minneapolis, Minn. (see line 2)	1939	Add'n	300	1	150	Stationary		D	
47.	Larchmont, N. Y.	1939	Close '69	120	2	60	Batch/Stationary		D	
48.	New Rochelle, N. Y.	1939		250	2	125	Stationary/Manually Stoked		WW F	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
49.	Pittsburgh, Pa.	1939	May Close '69	600	4	150	Batch/Stationary		None	
50.	Newport, R. I. (see line 314)	1939	Rebuilt '64	100	1	100	Manual		None	
51.	Providence, R. I. (see lines 95, 166)	1939		160	1	160	Batch/Man. Stoked/Stat. Dumping Grate	Yes	None	
52.	Durham, N. C.	1940	Closed	460	4	115	Stationary		D	
53.	Dayton, Ohio	1940		200			Cylindrical		None	
54.	New London, Conn.	1941		120			Rocking Grate		None	
55.	Atlanta, Ga. (see line 120)	1941		350	2	175	3 Grates/Rotary Kiln	U,O,I	D	Steam, Salvage
56.	Stamford, Conn. (see line 235)	1942		225	3	75	Batch/Rocker Type		S,B	
57.	Orlando, Florida	1942		150	2	75	Circular-Mech.		None	
58.	Middletown, Conn.	1943	Closed	60	1	60	Mech. Stoker	U	None	
59.	Detroit, Mich. (Cen.) (see lines 41, 228)	1943	Add'n	525	1	175	Circular		None	
60.	Staunton, Va.	1944	Closed	60	1	60	Batch/Circular/Mech. Stoked		None	
61.	Jacksonville, Florida (S. Side)	1945	Closed	120	1	120	Batch/Mech. Stoked/Circular	Yes	None	
62.	Youngstown, Ohio	1945		200	2	100	Batch/Man. Stoked		None	
63.	Lexington, Virginia	1945	Closed '54	30	1	30	Batch/Man. Stoked		None	
64.	Fond du Lac, Wis.	1945		90	3	30	Hearth		None	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Furnaces Mech. Draft	APC Equipment	By-Products
65.	Kenosha, Wis. (see line 283)	1945	Closed	300	2	150	Stationary		None	
66.	Bessemer, Ala.	1946	Closed	60	2	30	Batch/Man. Stoked		None	
67.	Beverly Hills, Calif.	1946	Closed '56	300	2	150	Batch/Circular/Mech. Stoked		None	
68.	Wash. Suburban Sanitary Com., Md.	1946	Closed '64	250	2	125	Batch/Circ. Mech. Stoked		None	
69.	Amsterdam, N. Y.	1946		120	2	60	Man. Stoked		None	
70.	Babylon, N. Y.	1946	Closed '55	90	1	90	Circular		None	
71.	Cheektowaga, N. Y.	1946		100	2	50	Batch/Mech. Stoked		None	
72.	Sidney, Ohio	1946	Closed	50	1	50	Batch/Circ./Mech. Stoked		None	
73.	Warwick, R. I.	1946		100	1	100	Batch/Mech. Stoked/Circ.		D	
74.	Norfolk, Va.	1946		400	4	100	Cylindrical		D	
75.	Green Bay, Wisconsin (see line 296)	1946		50	1	50	Batch/Stationary		D	
76.	Racine, Wis. (see lines 14, 169, 233)	1946	Rebuilt	220	(2 (1	80 60	Batch/Man. Stoked	I	D	
77.	Jacksonville, Florida	1947	Closed	350	2		Batch/Circ./Mech. Stoked		None	
78.	Aurora, Illinois	1947		40	2	20	Stationary		None	
79.	Holyoke, Mass.	1947		225	3	75	Rect. Cell/Manual Linkage Grate		D	
80.	Corning, N. Y.	1947		80	2	40	Batch/Circ./Mech. Stoked	U,O	D	
81.	Troy, N. Y.	1947	Closed '58	250	2	125	Batch/Circ./Mech. Stoked		None	
82.	West Seneca, N. Y.	1947	Closed '61	60	1	60	Batch/Circ./Mech. Stoked		None	
83.	East Cleveland, Ohio	1947	Closed '63	100	1	100	Batch/Circular/Mech. Stoked		None	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Furnaces Mech. Draft	APC Equipment	By-Products
84.	Houston, Texas (Velasco St.)	1947	Closed	300	2	150	Stationary/Cell		None	
85.	Jefferson Parish, La.	1948		90	1	90	Batch/Circ./Mech. Stoked	U	D	
86.	Fall River, Mass.	1948	Closed	85	1	85	Hearth		None	
87.	Pittsfield, Mass.	1948		180	2	90	Batch/Man. Stoked		D	
88.	Carmel, N. Y.	1948		40	1	40	Batch/Circ./Mech. Stoked	U	None	
89.	Liberty, N. Y.	1948	Closed '68	30	1	30	Batch/Man. Stoked		None	
90.	Tonawanda, N. Y.(Town) (see lines 9, 112)	1948	Add'n	140	2	70	Batch/Circ./Mech. Stoked		None	
91.	Barberton, Ohio	1948		100	2	50	Hearth		None	
92.	Cleveland Heights, Ohio	1948		150	2	75	Batch/Circ./Mech. Stoked	U	D	
93.	Columbus, Ohio	1948	Closed	150	3	50	Batch/Circ./Mech. Stoked		None	
94.	Lower Merion, Penn. (see lines 44, 362)	1948	Add'n	150	2	75	Rocking Grate Installed		None	
95.	Providence, R. I. (see lines 51, 166)	1948	Add'n	320	1	160	Batch/Double Traveling Grate		None	Steam
96.	Monroe, Wisc. (see line 297)	1948		30	1	30	Man. Stoked		None	
97.	West Bend, Wis.	1948	Closed	30	1	30	Batch/Circ./Mech. Stoked		None	
98.	Morgan City, La.	1949		30	1	30	Batch/Man. Stoked		None	
99.	Shreveport, La. (see lines 29, 250)	1949	Add'n	175	1	175	Stationary		None	Changed
100.	Salisbury, Md.	1949		125	1	125	Circ./Mech. Stoked		F	
101.	Lackawanna, N. Y.	1949		150	2	75	Stat. Man. Stoked/Dumping Grate		None	
102.	Mt. Kisco, N. Y.	1949		40	1	40	Batch/Man. Stoked	U	None	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
103.	Mt. Vernon, N. Y.	1949		600	4	150	Batch/Circ./Mech. Stoker	U	None	
104.	Collingswood, N. J.	1949	Closed	40	1	40	Batch/Circ./Mech. Stoked		None	
105.	Meadville, Pa.	1949		80	1	80	Batch/Circ./Mech. Stoked	U	D	
106.	West Mifflin, Pa.	1949		40	3	1/20 2/10	Stationary		None	
107.	Houston, Texas (Paterson) (see line 167)	1949	Closed	300	2	150	Cell/Stationary		None	
108.	Alhambra, Calif.	1950	Closed '61	150	1	150	Batch/Circ./Mech. Stoked	U,I	None	
109.	Jacksonville, Fla.	1950		300	2	150	Batch/Circ./Mech. Stoked	SB		
110.	Gretna, La.	1950		100	2	50	Batch/Circ./Mech. Stoked	U	D	
111.	Gloucester City, N. J.	1950	Closed '64	60	1	60	Batch/Circ./Mech.Stoked		S	
112.	Tonawanda, N. Y. (Town) (see lines 9, 90)	1950	Add'n	200	1	60	Batch/Circ./Mech. Stoked		None	
113.	Ambridge, Pa.	1950	Closed	150	2	75	Stationary		None	
114.	Phila., Pa. (Southeast) (see line 179)	1950		300	2	150	Batch/Circ./Mech. Stoked		D-SB	
115.	Phila., Pa. (Bartram)	1950		300	2	150	Batch/Circ./Mach. Stoked		D,WW	
116.	Arlington, Va. (see lines 216, 330)	1950		300	2	150	Batch/Mech. Stoked		WW	
117.	Pomona, Calif.	1951	Closed '55	225	2	112.5	Batch/Circ/Mech. Stoked/MB		None	
118.	Derby, Conn.	1951	Closed	60	1	60	Circ.		None	
119.	Miami, Fla.	1951		900	6	150	Cont./Circ./Mech. Stoked	I	WW	Steam
120.	Atlanta, Ga. (Mayson) (see line 55)	1951	Add'n	350	2	175	3 Grates/Rotary Kiln	U,O,I	D	
121.	St. Louis, Mo. (South Bend)	1951		400	4	100	Batch/Rocking Grate	Yes	D	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
122.	Port Chester, N. Y.	1951		120	2	60	Batch/Circ./Mech. Stoked	O	D,F	Steam
123.	Yonkers, N. Y.	1951		450	3	150	Batch/Circ./Mech. Stoked	Yes	D	
124.	Lakewood, Ohio	1951		150	2	75	Batch/Man. Stoked	Yes	D	
125.	Lima, Ohio	1951	Closed	200	2	100	Batch/Stationary		None	
126.	Warren, Ohio		Closed '67	100	3	33+	Batch/Shaker		None	
127.	Glendale, Calif. (see line 185)	1952	Closed	90	1	90	Batch/Circ./Mech. Stoked		None	
128.	Santa Monica, Calif.	1952	Closed	300	4	75	Batch/Man. Stoked	U,O,I	None	
129.	Waterbury, Conn.	1952		300	2	150	Batch/Circ./Mech. Stoked	U	WW	Drying, Sewage, Sludge
130.	Brookline, Mass.	1952		300	2	150	Batch/Mech. Stoked/ Rabble Arm	Yes	D,SB	
131.	Lawrence, Mass.	1952		300	2	150	Batch/Circ./Mech. Stoked	I	C	Steam
132.	Somerville, Mass.	1952		450	3	150	Batch/Circ./Mech. Stoked		SB	
133.	Hempstead, N. Y.	1952		700	4	175	Batch/Circ./Mech. Stoked	I	C,WB	Steam
134.	North Hempstead, N. Y.	1952		200	2	100	Batch/Circ./Mech. Stoked		S,C	
135.	Rocky River, Ohio	1952	Closed	50	1	50	Batch/Hearth		None	
136.	Bloomsburg, Penna.	1952	Closed '66	60	1	60	Batch/Circ./Mech. Stoked	Yes	None	Steam
137.	Los Angeles, Cal. (Gaffey St.)	1953	Closed	200	2	100	Batch/Circ./Mech. Stoked	Yes	D	
138.	S. E. Oakland Co., Mich. (see line 291)	1953		450	3	150	Batch/Circ./Mech. Stoked	Yes	D	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Furnaces Mech. Draft	APC Equipment	By-Products
139.	Pennsauken, N. J. (see line 6)	1953	Closed	60	1	60	Batch/Circ./Mech. Stoked		S	
140.	Woodbridge, N. J.	1953	Closed '62	300	2	150	Batch/Stationary/Drop Grate		None	
141.	Harrison, N. Y.	1953		150	2	75	Batch/Circ./Mech. Stoked	U	F	
142.	Long Beach, N. Y.	1953		200	2	100	Batch/Circ./Mech. Stoked		EB	
143.	New York, N. Y. (Gansevoort)	1953		1000	4	250	Cont./Double Travel. Grate		D,WW	
144.	Cheviot, Ohio	1953		60	2	30	Batch/Stationary		None	
145.	Allentown, Pa. (see lines 4, 23	1953	Add'n	270	1	90	Stationary/Conv. Boiler		None	
146.	Erie, Pa.	1953		100	2	50	Batch/Circ./Mech. Stoked		D	
147.	Fort Worth, Texas	1953	Closed	260	2	130	Batch/Circ./Mech. Stoked		None	
148.	Milwaukee, Wis. (Green Bay Ave.)	1953		300	2	150	Batch/Circ./Mech. Stoked	U,O	WW	Steam
149.	Hartford, Conn.	1954		600	4	150	Circ./Mech. Stoked	U	D	
150.	New Britain, Conn.	1954		300	2	150	Cylindrical Grate		None	
151.	Ft. Lauderdale, Fla.	1954		250	2	125	Circ./Mech. Stoked		None	
152.	Skokie, Ill.	1954		150	2	75	Batch/Impact Stoker	Nat.	WW	
153.	Newton, Mass. (see line 351)	1954		240	2	120	Batch/Rocking Grate		SB	
154.	Ecorse, Mich.	1954	Closed	90	1	90	Batch/Circ./Mech. Stoked		None	
155.	St. Louis Park, Minn.	1954	Closed	150	2	75	Batch/Rocking Grate	Yes	None	
156.	Omaha, Neb.	1954		375	3	125	Batch/Cell Type/Rocking Grate	U,O	D	
157.	Princeton, N. J. (see line 20)	1954	Add'n	120	1	60	Batch/Circ.		None	
158.	Buffalo, N. Y.	1954		600	3	200	Batch/Circ./Mech. Stoked	Yes	D	
159.	New York, N. Y. (S. Shore)	1954		1000	4	250	Cont./Double Trav. Grate	U,O	D,F	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
160.	Huntington, N. Y.	1954		150	1	150	Batch/Rocking Gr./Man. Oper.	Yes	S	
161.	Berea, Ohio	1954	Closed '66	50	1	50	Batch/Man. Stoked		None	
162.	Cincinnati, Ohio (West Fork)	1954		500	4	125	Batch/Circ./Mech. Stoked		D	
163.	South Euclid, Ohio	1954	Closed	100	2	50	Batch/Rocking Grate F & E	U	None	
164.	Youngstown, Ohio	1954	Add'n	100	1	100	Batch/Man. Stoked	Yes,I	D,Sc	
165.	Philadelphia, Pa. (Harrowgate) (see line 1)	1954	Rebuilt	300	2	150	Batch/Circ./Mech. Stoked		D,WW	
166.	Providence, R. I. (see lines 51, 95)	1954	Rebuilt	320	1	160	Cont./Double Trav. Grate	Yes,I	None	Steam
167.	Houston, Texas (Paterson) (see line 107)	1954	Closed	300	2	150	Cell/Stationary Grate		None	
168.	Kenosha, Wis.	1954	Closed	120	2	60	Manual, Stationary		None	
169.	Racine, Wis. (see lines 14, 76, 233)	1954	Add'n	60	1	60	Rocking Gr. F & E	I,U	D,WW	
170.	Wash., D. C. (#3 Mt. Olivet)	1954		500	4	125	Batch/Rocking Grate	U	D	
171.	Framingham, Mass.	1955		200	2	100	Cont./Single Traveling Grate	U,I	S,Sc	
172.	Perth Amboy, N. J. (see line 12)	1955	Add'n	150	1	100	Stationary		None	
173.	Red Bank, N. J. (see line 15)	1955	Add'n	120	1	60	Hearth		WW	
174.	Babylon, N. Y.	1955		300	2	150	Batch/Circ./Mech. Stoked		S	
175.	Rochester, N. Y. (West Side)	1955		450	3	150	Batch/Circ./Mech. Stoked		WW,F	
176.	Bedford, Ohio	1955	Closed	50	1	50	Dump/Stationary		None	
177.	Abington, Pa.	1955		200	2	100	Batch/Rocking Grate	U,O	D	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
178.	Philadelphia, Pa. (Bartram) (see line 115)	1955	Add'n	450	2	125	Batch/Circ./Mech. Stoked		D,WW	
179.	Philadelphia, Pa. (Southeast) (see line 114)	1955	Add'n	300	2	150	Batch/2-Trav.		WW	
180.	Red Lion Borough, Pa.	1955		60	1	60	Batch/Circ./Mech. Stoked		WW	
181.	Houston, Texas (Holmes Rd.)	1955	Closed	300	1	300	Cell-Stationary		None	
182.	Kewaskum, Wisc.	1955		24	1	24	Batch/Circ./Mech. Stoked		WW	
183.	Merrill, Wisc.	1955		35	1	35	Rocking Grate	Yes	D	
184.	Milwaukee, Wisc. (Lincoln Ave.)	1955		300	2	150	Batch/Rocking Gr.	U,O	WW	Steam
185.	Glendale, Calif. (see line 127)	1956	(Add'n) Closed	180	1	90	Batch/Ram Feed/Rect. Grate	U,I	WB,S	
186.	Los Angeles, Calif. (Lacy St.)	1956	Closed	320	2	160	Batch/Man. Stoked	O,I	D,WW	
187.	East Hartford, Conn. (see line 333)	1956		200	2	100	Batch/Rocking Grate	Nat.	D	
188.	New Canaan, Conn.	1956	Rebuilt	50	1	50	Batch/Circ./Mech. Stoked	U	D	
189.	West Hartford, Conn.	1956		350	2	175	Batch/Mech. Stoked/Circ.	U	D	Steam
190.	Chicago, Ill. (Medill)	1956		720	4	180	Batch/Rocking Grate	Yes	S	Steam
191.	Baltimore, Md. (#4)	1956		800	4	200	Batch/Rocking Gr.	U,O	D	
192.	St. Louis, Missouri (North Side)	1956		400	4	100	Rocking Grate/F&E/Rect. Cell	Yes	D	
193.	Binghamton, N. Y.	1956		300	2	150	Batch/Circ./Mech. Stoked	U	D	
194.	Niagara Falls, N. Y.	1956		240	2	120	Batch/Circ./Mech. Stoked	Yes	D	
195.	Oyster Bay, N. Y. (Bethpage)	1956		500	4	125	Batch/Rect. Cell	U,I	SB	Steam
196.	Poughkeepsie, N. Y.	1956	Rebuilt	200	2	100	Batch/Circ./Mech. Stoked	U	D	
197.	Rochester, N. Y. (E. Side)	1956		600	4	150	Batch/Circ./Mech. Stoked		WW,F	
198.	White Plains, N. Y.	1956		400	2	200	Batch/Rocking Grate	U	WW	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
199.	Euclid, Ohio	1956		200	2	100	Batch/Rocking Grate	U,O	WB	
200.	Maple Hts., Ohio	1956	Closed '67	150	2	75	Batch/Rocking Grate		None	
201.	Parma, Ohio	1956		225	2	112.5	Batch/Rocking Grate	U	SB	Hot Water
202.	Philadelphia, Pa. (Northeast)	1956		600	4	150	Batch/Circ./Mech. Stoked	U,I	D,WW	
203.	Fort Worth, Texas	1956	Closed	190	2	95	Batch/Circ./Mech. Stoked		None	
204.	Alexandria, Va.	1956	Standby	200	2	100	CellType/Rocking Grate	Yes	D	
205.	West Allis, Wisc.	1956		200	2	100	Batch/Rocking Grate		S,EB	
206.	Whitefish Bay, Wisc.	1956		80	2	40	Cont./Rect. Cell		D,WW	
207.	Coral Gables, Fla.	1957		300	2	150	Batch/Circ./Mech. Stoked		WW	
208.	Lexington, Ky.	1957		200	2	100	Batch/Circ./Mech. Stoked	Yes	D	
209.	Louisville, Ky. (see line 321)	1957		750	3	250	Cont./Rot. Kiln		S	Steam, Salvage Cans
210.	Worcester, Mass.	1957		450	3	150	Batch/Circ./Mech. Stoked		None	
211.	Detroit, Mich. (Northwest) (see line 40)	1957	Rebuilt	450	2	225	Batch/Rocking Grate		WW	
212.	Detroit, Mich. (St. Jean) (see line 39)	1957	Rebuilt	350	2	175	Batch/Rocking Grate		WW	
213.	Hamtramck, Mich.	1957	One Closed '66	100	2	100	Rocking Grate		S	
214.	Jersey City, N. J.	1957		600	4	150	Batch/Circ./Mech. Stoked	U	Sc	Steam
215.	New York, N. Y. (74th St.)	1957	Rebuilt	660	3	220	Cont./Double Traveling Gr.	U,O,I	C	Steam
216.	Arlington, Va. (see lines 116, 330)	1957	Add'n	600	2	150	Batch/Circ./Mech. Stoked		SB	
217.	Bridgeport, Conn.	1958		300	2	150	Batch/Circ./Mech. Stoked	U,O	W,S,SB	
218.	New Milford, Conn.	1958	Closed	75	1	75	Rolling Grate		None	
219.	Hollywood, Fla.	1958		450	2	225	Batch/Oscillating Grate	Yes	WB,S	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces			Mech. Draft	APC Equipment	By-Products
					No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate			
220.	Evanston, Ill.	1958		180	2	90	Batch/Rocking Grate	Yes	D	
221.	Melrose Park, Ill.	1958		250	1	250	Batch/Impact		None	
222.	Schiller Park, Ill.	1958		250	1	250	Modified Internatl.		None	
223.	Stickney, Ill.	1958		500	2	250	Cont./Grate & Kiln		WB	
224.	Indianapolis, Indiana	1958		450	3	150	Batch/Circ./Mech. Stoked		WW	Steam
225.	New Orleans, La. (Fla. Ave.)	1958		400	2	200	Batch/Rocking Grate	U	D,S	
226.	Marblehead, Mass.	1958		90	1	90	Batch/Rocking Grate	U	WW	
227.	Watertown, Mass.	1958		250	2	125	Batch/Circ./Mech. Stoked	I,D,O,U	Sc,C	
228.	Detroit, Mich. (Central) (see lines 41, 59)	1958	Modification	525	3	175	Batch/Rocking Grate		WW	
229.	Tonawanda, N. Y. (see line 43)	1958	Add'n	100	2	50	Rocking Grate		D	
230.	Durham, N. C.	1958	Closed	300	2	150	Batch/Man. Stoked/Hydraulic Dump	U	D	
231.	Fort Worth, Texas	1958	Closed	125	2	62.5	Batch/Rocking Grate		None	
232.	Neenah-Menasha, Wisc.	1958		300	2	150	Cont./Single Trav. Grate		S	
233.	Racine, Wisc. (see line 14, 76, 169)	1958	Add'n	120	1	60	Rocking Grate	I,U	D,WW	
234.	Shorewood, Wisconsin	1958		60	2	30	Batch/Rocking Grate	U,O	WW	
235.	Stamford, Conn. (see line 56)	1959	Add'n	125	1	125	Batch/Rocking Grate	U	SB	Steam
236.	Chicago, Ill. (Calumet)	1959		1200	6	200	Batch/Rocking Grate		WW	Steam
237.	New Albany, Indiana	1959		160	2	80	Cont./Single Trav. Grate	U,O	D	Steam
238.	Belmont, Mass.	1959		150	2	75	Batch/Circ./Mech. Stoked	U,I,O	SB	Salvage
239.	Boston, Mass.	1959		900	6	150	Batch/Rocking Gr	U,I	C	Steam

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Furnaces Mech. Draft	APC Equipment	By-Products
240.	New Bedford, Mass.	1959		225	2	112.5	Rocking Grate		None	
241.	Waltham, Mass.	1959		200	2	100	Rocking Grate	Nat.	D	
242.	Wellesley, Mass.	1959		150	2	75	Batch/Rocking Grate		F	
243.	New York, N. Y. (Betts Ave.)	1959	Rebuilt	1000	4	250	Cont./Double Trav. Gr.	U,O	D,F	
244.	New York, N. Y. (Greenpoint)	1959		1000	4	250	Cont./Double Trav. Grate	U,O	None	Steam
245.	Rye, N. Y.	1959		150	2	75	Batch/Circ./Mech. Stoked	U	WB	
246.	Scarsdale, N. Y.	1959		150	2	75	Batch/Circ./Mech. Stoked	U	WB	
247.	Whitemarsh, Pa. (see line 356)	1959		300	1	300	Batch/Charging Ram/Recip. Grate	U,O,I	Sc	
248.	Miami, Fla.	1960		300	1	300	Cont./Grates and Rotary Kiln	U,O	SB	
249.	Winchester, Kentucky	1960		100	2	50	Batch/Reciprocating Grate	I	SB	
250.	Shreveport, La. (see line 29, 99)	1960	Rebuilt	250	1	250	Rocking Grate		S	
251.	Garden City, Mich.	1960		500					WW	
252.	Huntington, N. Y.	1960		150	1	150	Batch/Rocking Gr./Man. Oper.		None	
253.	New Rochelle, N. Y.	1960		150	1	150	Batch/Rocking Grate		WW,F	
254.	North Tonawanda, N. Y.	1960	Closed '69	100	1	100	Batch/Reciproc.		None	
255.	Cleveland, Ohio	1960		500	4	125	Batch/Rocking Grate	I	WW	
256.	Bradford, Pa.	1960		200	2	100	Batch/Rocking Grate	U,O	D	Steam
257.	Delaware County, Pa. (#1)	1960		500	2	250	Cont./Double Trav. Grate	U,O	D,F	
258.	Philadelphia, Pa. (NW)	1960		600	2	300	Cont./Double Trav. Grate	U,O,I	S,C	
259	Woonsocket, R. I.	1960		160	2	80	Batch/Circ./Mech. Stoked	U	D	
260.	Bridgeport, Conn.	1961		200	2	100	Batch/Rocking Gr.		S	
261.	Honolulu, Hawaii	1961		220	2	110	Batch/Recipr. Grate		WB	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
262.	Dedham, Mass.	1961		100	2	50	Batch/Rocking Grate	U,O	SB	
263.	Winchester, Mass.	1961		100	2	50	Batch/Rocking Grate	U,O,I	WB,S,C	
264.	River Rouge, Mich.	1961		60	1	60	Batch/Rocking Grate		S,WW	
265.	New York, N. Y. (Hamilton Ave.)	1961		1000	4	250	Cont./Double Traveling Grate	U,O	SB,D	Steam
266.	New York, N. Y. (SW Brooklyn)	1961		1000	4	250	Cont./Doubl. Trav. Grate	U,O	S	
267.	Norwood, Ohio	1961		150	2	75	Batch/Recipr. Grate	U,O,I	S	
268.	Sharonville, Ohio (see line 340)	1961		350	1	350	Cont./Double Trav. Grate	I	Sc.	
269.	Delaware County, Pa. (#2)	1961		500	2	250	Cont./Double Trav. Grate		WB	
270.	DePere, Wisconsin	1961		225	1	150	Hearth	Yes	D,S	
	(see line 344)				1	75	Rect. Cell/Rocking Grate	Yes	D,S	
271.	Wauwatosa, Wisc.	1961		165	2	82.5	Batch/Rocking Grate	Yes	WW	
272.	Washington, D. C. (Ft. Totten)	1961		500	4	125	Batch/Rocking Grate	U	D	
273.	Darien, Conn.	1962	(Add'n) Closed	70	1	70	Batch/Rocking Grate	U	WW	
274.	Norwalk, Conn.	1962		360	2	180	Cont./Single Trav. Gr.	U,O	SB	
275.	Honolulu, Hawaii	1962		220	2	110	Batch/Reciprocating Grate		Sc, WW	
276.	New Orleans, La. (7th St.)	1962		400	2	200	Batch/Rocking Grate	U	D,S	
277.	Salem, Mass.	1962		230	2	115	Batch/Circ.	Nat.	SB	
278.	Eastchester, N. Y.	1962		200	2	100	Batch/Rocking Grate	U	WB,S	
279.	Islip, N. Y.	1962		300	2	150	Cont./Single Travl. Grate	U,O,I	C	
280.	Valley Stream, N. Y.	1962		200	2	100	Cont./Single Trav. Grate	U,O	WW	
281.	Woodville, Ohio	1962		12	1	12	Batch/Man. Stoked		None	
282.	Delaware County, Pa. (#3)	1962		500	2	250	Cont./Double Trav. Grate	U,O	WB, SB	

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
283.	Kenosha, Wisc. (see line 65)	1962	Closed	220	(2	50				
					(2	60	Shaker		None	
284.	Greenwich, Conn. (see line 37)	1963	Add'n	400	1	250	Cont./Rocking Grate	U,O	SB	
285.	New Haven, Conn.	1963		720	3	240	Cont./Double Trav. Grate	U,O,S	WB	
286.	Atlanta, Ga.	1963		500	2	250	Cont./3 grates & kiln	U,O	WB,S,SB	Metals, Rotat?
287.	Chicago, Ill. (SW)	1963		1200	4	300	Rotary Kiln/Recip. Grate	U,I	WB,S,SB	Steam
288.	New Orleans, La. (Algiers)	1963		200	1	200	Cont./Double Trav. Grate	U,O,S	C	
289.	Watertown, Mass.	1963		100	2	50	Circ.	I	S,Multiple Cyclone	
290.	Detroit, Mich. (24th St.) (see line 42)	1963	Rebuilt	500	2	250	Batch/Rocking Grate		WW	
291.	S.E. Oakland Co., Mich. (see line 138)	1963	Rebuilt	600	2	300	Cont./Double Trav. Grate	U,O	SB	Steam
292.	Garden City, N. Y.	1963		175	2	87.5	Cont./Recipr.	U,O	WW	Steam
293.	Rocky River, Ohio	1963	Closed	60	1	60	Batch/Reciprocating Grate		D,S	
294.	Ambridge, Pa.	1963		150	2	75	Rocking Grate		None	
295.	Portsmouth, Virginia	1963		350	2	175	Batch/Rocking Grate	Yes	WW	
296.	Green Bay, Wisc. (see line 75)	1963	Add'n	150	2	50	Batch/Stationary		D	
297.	Monroe, Wisc. (see line 96)	1963	Add'n	60	1	30	Batch/Man. Stoked		None	
298.	Broward City, Fla.	1964		300	2	150	Cont./Recipr. Grate	U,O,I	Sc	Metal
299.	Clearwater, Fla.	1964		300	2	150	Cont./Recipr. Grate	U,O,I	WW	
300.	Orlando, Fla.	1964		250	2	125	Batch/Oscillating Grate	U,O	SB	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
301.	DeKalb County, Ga.	1964		600	2	300	Cont./Rotary Kiln	U,O	S	
302.	Bloomington, Ind.	1964		100	1	100	Batch/Recipr. Grate	U,I	SB	
303.	Frankfort, Kentucky	1964		150	2	75	Batch/Reciprocating Grate	I	SB	
304.	Jefferson Parish, La.	1964		400	2	200	Cont./Double Trav. Grate	U,O,S	C	
305.	Lowell, Mass.	1964		400	2	200	Cont./Double Trav. Grate	O,I,U	S	
306.	Central Wayne Co., Mich.	1964		500	2	250	Recipr.		SB	
307.	Dearborn, Mich.	1964		500	2	250	Cont./Recipr. Grate	U,O,I	SB	
308.	Trenton, Mich.	1964		100	1	100	Batch/Recipr. Grate		S	
309.	Beacon, N. Y.	1964		100	2	50	Batch/Rocking Grate	U,O	SB	
310.	Canajoharie, N. Y.	1964		50	1	50	Batch/Circ./Mech. Stoked	U	SB	
311.	Freeport, N. Y.	1964	Rebuilt	150	2	75	Batch/Rock. Grate-Constant Flow	U,O	WB	
312.	Cincinnati, Ohio (Center Hill)	1964		500	2	250	Cont./Double Trav. Grate	U,O	WW	
313.	Ewing Township, Pa.	1964		240	1	240	Cont./Single Traveling Grate	U,O	D	
314.	Newport, R. I. (see line 50)	1964		120	1	120	Rocking Grate		None	
315.	Pawtucket, R. I.	1964		400	2	200	Cont./Double Trav. Grate		WW	
316.	Roanoke, Va.	1964	Rebuilt	200	2	100	Batch/Reciprocating Grate	U,O	D	
317.	Charleston, W. Va.	1964		300	2	150	Batch/Recipr. Grate	U,O,I	SB	
318.	Nekoosa, Wisc.	1964		60	1	60	Batch/Reciprocating Grate	U	WB,S	
319.	Broward Cty., Fla.	1965		300	2	150	Cont./Recipr. Grate	U,I,O	Sc	Metal
320.	Dodge City, Kansas	1965		35	1	35	Hearth		None	
321.	Louisville, Kentucky (see line 209)	1965	Add'n	1000	1	250	Cont./Rotary Kiln	Yes	S	Steam, Cans
322.	Paris, Kentucky	1965		100	2	50	Batch/Reciprocating Grate		SB	

TABLE I–1 (Continued)

					Furnaces					
Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	No.	Capacity Ea. T/24 Hrs.	Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
323.	Montgomery County, Md.	1965		1050	3	350	Cont./Double Trav. Grate	U,O,I	C	Steam
324.	Weymouth, Mass.	1965		300	2	150	Batch/Circ./Mech. Stoked	U	SB	
325.	Ewing, N. J.	1965		240	1	240	Single Trav./Horiz.	O,U	D	
326.	Newburgh, N. Y.	1965		240	2	120	Cont./Rock. Grate-Const. Flow	U,O,S	SB	
327.	Oyster Bay, N. Y.	1965		500	2	250	Cont./Rock. Grate-Cons. Flow	U,O	SB	
328.	Ramapo, N. Y.	1965	Add'n	200	1	200	Batch/Rect.	Yes	SB	
329.	Amarillo, Texas	1965		250	2	125	Batch/Ram Feed/Recipr. Grate		WW	
330.	Arlington, Va.	1965	Add'n	750	1	150	Circ./Mech. Stoked		SB	
	(see lines 116, 216)									
331.	Port Washington, Wisc.	1965		75	1	75	Batch/Recipr. Grate	U,I	SB	
332.	Sheboygan, Wisc.	1965		240	2	120	Cont./Rock. Gr./Const. Flow	U,O	S	
333.	E. Hartford, Conn.	1966	Add'n	350	1	150	Batch/Rock. Grate	I,O	D,SB	
	(see line 187)									
334.	Ft. Lauderdale, Fla.	1966		450	2	225	Cont./Recipr. Grate	U,O,I	S	
335.	Picayune, Miss.	1966		144	1	144			WW	
336.	Babylon, N. Y.	1966		400	2	200	Cont./Rock. Gr./Const. Flow	U,O	S	
337.	Hempstead, N. Y.	1966		750	1	150	Cont./Rock. Grate/Const.	U,O,I	SB	
	(see line 187)				2	300				
338.	Huntington, N. Y.	1966		150	1	150	Cont./Rock. Gr–Const. Flow	U,O	D,Sc	
339.	North Hempstead, N. Y.	1966		600	2	200	Rock. Grate-Const. Flow	I	C	
					1	200	Double Trav. Grate			
340.	Sharonville, Ohio	1966	Add'n	300	2	150	Batch/Recipr. Grate		WB	
	(see line 268)									
341.	Philadelphia, Pa. (E. Cent.)	1966		600	2	300	Cont./Double Trav. Grate	I,O,U	SB,WB	
342.	Ogden, Utah	1966		300	2	150	Single Traveling Grate		S	
343.	Alexandria, Va. (#2)	1966		300	2	150	Cont./Rock, Gr. Const. Flow	U,O	D,SB	
344.	DePere, Wisc.	1966		300	1	300	Hearth		S	
	(see line 270)									

TABLE I–1 (Continued)

Line No.	Location	Year Built	1969 Status	Plant Capacity Tons Per 24 Hrs. (incl. addns)	Furnaces No.	Furnaces Capacity Ea. T/24 Hrs.	Furnaces Type Furnace and Grate	Mech. Draft	APC Equipment	By-Products
345.	Green Bay, Wisc.	1966		200	2	100	Batch/Stationary		SB	
346.	West Haven, Conn.	1967		300	2	150	Cont./Rock, Gr.-Const. Flow	U,O,I	S,C	
347.	St. Petersburg, Fla.	1967		500	2	250	Batch/Rock. Gr.-Cons. Flow	U,O,I	SB	
348.	Tampa, Fla.	1967		900	3	300	Cont./Kiln	U,O,I	Sc	
349.	Lexington, Ky.	1967		150	1	150	Batch/Rocking Grate	U,O	D	
350.	New Orleans, La. (East)	1967		400	2	200	Cont./Rock. or Recipr. Grate	U,O,S	D,C	
351.	Newton, Mass. (see line 153)	1967		500	2	250	Cont./Triple Trav. Grate	U,O	WW	
352.	Troy, Ohio	1967		150	1	150	Batch/Reciproc.		SB	
353.	Houston, Texas (Holmes Rd.)	1967		800	2	400	Cont./Triple Trav. Gr.		Sc	
354.	Stratford, Conn.	1968		240	2	120	Cont./Single Trav. Grate	U,O,S	SB	
355.	Miami County, Ohio	1968		150	1	150	Cont./3 Pusher Grates	I,U,O	Sc	
356.	Whitemarsh, Pa. (see line 247)	1968	Rebuilt	300	1	300	Cont./Rocking Grate	U,O,I	SB	
357.	Norfolk, Va.	1968		360	2	180	Cont./Recipr. Grate	U,O,I	C, Waterwall Boiler	
358.	Oshkosh, Wisc.	1968		350	2	175	Cont./Recipr./Triple Grate	I,O,U	S	
359.	Dade County, Fla.	1969 (est.)		300			Reciprocating		Sc	
360.	East Chicago, Ind.	1969 (est.)		450			Reciprocating		Sc	
361.	New Orleans, La. (7th St.)	1969	Rebuilt	400	2	200	Cont./Double Trav. Gr.	U,O,I	S,C	
362.	Lower Merion, Pa. (see lines 44, 94	1969		250	2	125	Cont./Rock. Gr./Cons. Flow		Sc	
363.	Braintree, Mass.	1970 (est.)		480	2	240				Steam
364.	Fall River, Mass.	U.C.		600	2	300	Double Grate/Rock, or Recipr.		C	

TABLE I–1 (Continued)

KEY TO ABBREVIATIONS

Mechanical Draft

Yes – Forced draft reported, but distribution not indicated.

U – Forced underfire. Includes cone cooling air for circular furnaces

O – Forced overfire

S – Forced side fire

I – Induced draft

Fly Ash Removal

C – Cyclones

D – Dry expansion chamber

F – Fly ash screen

S – Water sprays

SB – Spray or wet baffles (close-spaced baffles)

Sc – Scrubber

WB – Water bottoms or ponds in chambers

WW – Wet walls (transverse, wide-spaced baffles)

A particular problem arises in the area of APC systems concerning the definition "wetted wall" or "wetted baffle" systems. In many older plants, the collection of particulate matter in settling chambers was assisted by incorporation of transverse baffle walls, wetted (to some extent) with sprays. Many plants so equipped are said to have "wetted baffles." In more recent years, it has been recognized that efficient air pollution control required closer baffle spacings and better baffle wetting. As a result, vertical columns of metal or refractory, wetted by coarse water sprays, were introduced. To some, these are "wetted baffles"; to others, "scrubbers." A third APC system used in plants is comprised of plate-type wet collectors. These, like the close-spaced wetted baffles, are called "scrubbers." The resulting confusion casts some doubt on the accuracy of this part of Table I-1. Often in the course of interviews, from the questionnaire, and through some telephone solicitation, incorrect device designations were identified and corrected. In other cases, engineering judgment or contacts with second parties were used to establish equipment designations. To our knowledge, however, the compilation represents the most complete inventory available, including several units not reported in References 1 and 2.

2. Design Trends

Shifts in the design basis for municipal incinerator plants reflect the interaction of local solid waste disposal needs, exploitation of advancements in technology by the design engineers, and local economics. The small number of incinerator plants built in any one year (typically eight to fifteen) and the variability of the three factors across the country obscures design changes in any short-term observation. To perceive general changes in incinerator design criteria, a comprehensive historical approach is helpful. Although the data bank used is somewhat less comprehensive than used here, the reader is urged to review the paper by Stephenson and Cafiero[1]* where a similar development of design trends is presented. Their paper describes a number of design features (such as refuse storage and handling systems) which are not reported here.

a. New Construction

Figure I-1 indicates the annual incinerator construction over the past 30 years. It can be seen that the majority of the plants now operating in the country were built in the late 1950's and the early 1960's. Beginning in about 1965, a decline in the installation of new capacity is seen. This same time period, however, has seen an increasing awareness on the part of municipal governments, that new solid waste disposal facilities are needed. Two interpretations of the downward trend in incineration and the increasing pressures for new solid waste disposal facilities are offered. It could be argued that the decline indicates an

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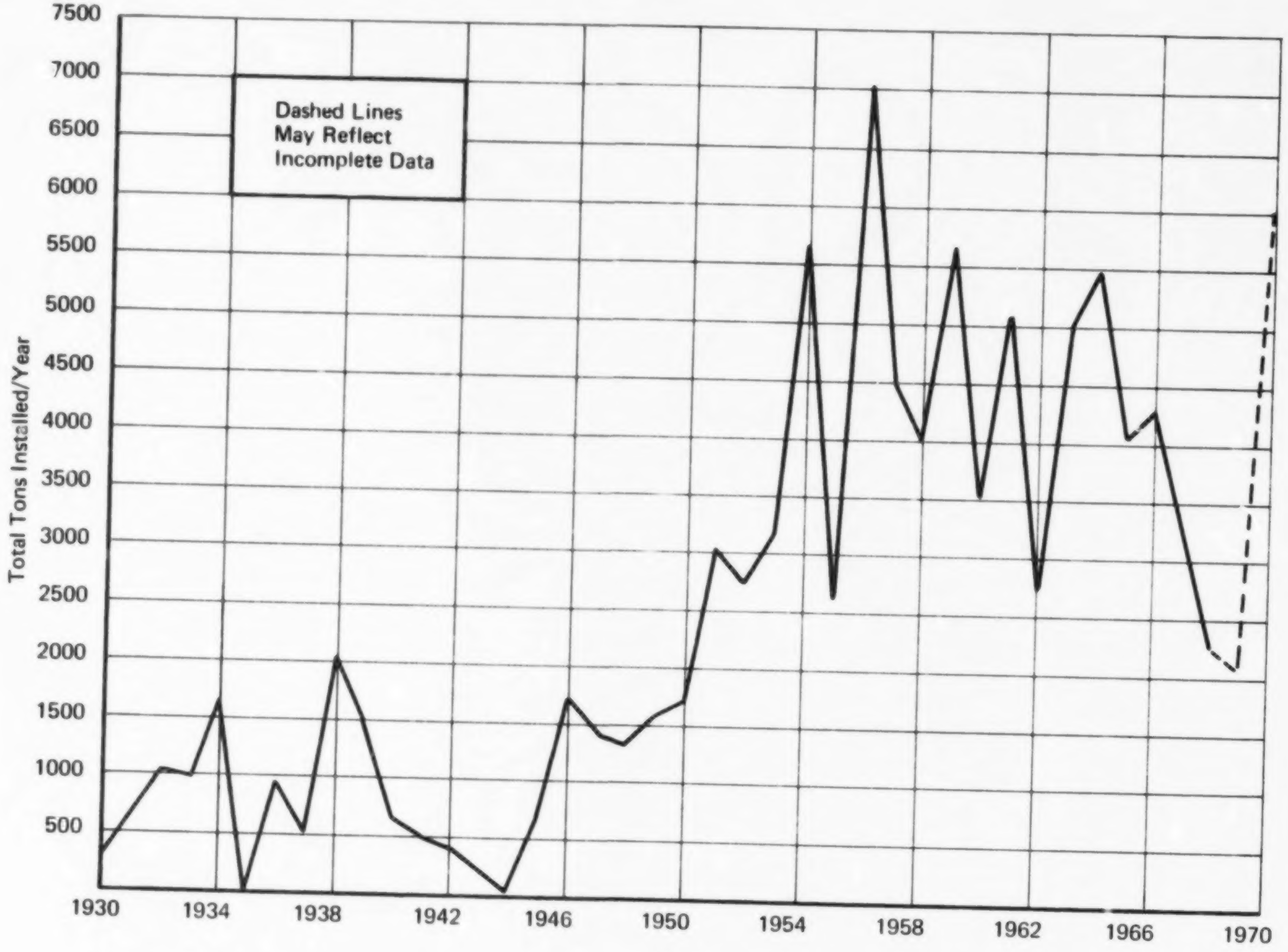
*All superscript numbers refer to the list of references (Section D) at the end of this appendix.



Source: Table I–1

FIGURE I–1 TOTAL ANNUAL ADDITIONS TO UNITED STATES INCINERATOR CAPACITY (See Table I–1, Vol. I)

unwillingness on the part of municipal governments to consider incineration. Alternatively, however, other factors may have had a more significant effect:

- Intense pressures have been placed upon municipal funds to respond to pressing social needs;
- Diminishing availability of money and high bond interest rates;
- An unwillingness to commit on incineration (with its high cost) in the hope that current publicly and privately sponsored research programs will provide inexpensive and high performance waste disposal concepts.

The first two factors may be relatively short-term: the mounting waste disposal crisis will soon demand action, almost at any cost. The third factor, may also be relatively short-lived. Current research results do not offer the promise of providing low cost alternatives to incineration. It is envisioned, therefore, that the previously depressed rate of incinerator construction will shift and that the forthcoming years will see an increase in the rate of installation of new capacity.

b. Plant and Furnace Capacity

Figure I-2 shows the range of total plant capacities built over the last 29 years. Although the trend of maximum plant size appears to be leveling off or decreasing, the average plant size is steadily increasing and is now approaching 400 tons per day. This trend and a corresponding decrease in the construction of small plants reflect the economic pressures which proscribe the construction of small facilities with their attendant high capital and operating cost.

Figure I-3 indicates the range of furnace capacities over the past 29 years. The trend towards larger furnace sizes also arises from improved investment and operating economics. The implications of these changes on air pollution are also significant, based on the analysis of the causes of air pollution presented in Section V and APC economics as presented in Section VII.B. Larger incinerator furnaces produce moderately higher particulate loadings and slightly increased nitrogen oxide emissions. Investments in pollution control equipment, however, will be lower for the larger plants (per tons per day of capacity). As a result, greatly improved air pollution control equipment can be installed on these larger furnaces at very modest unit costs.

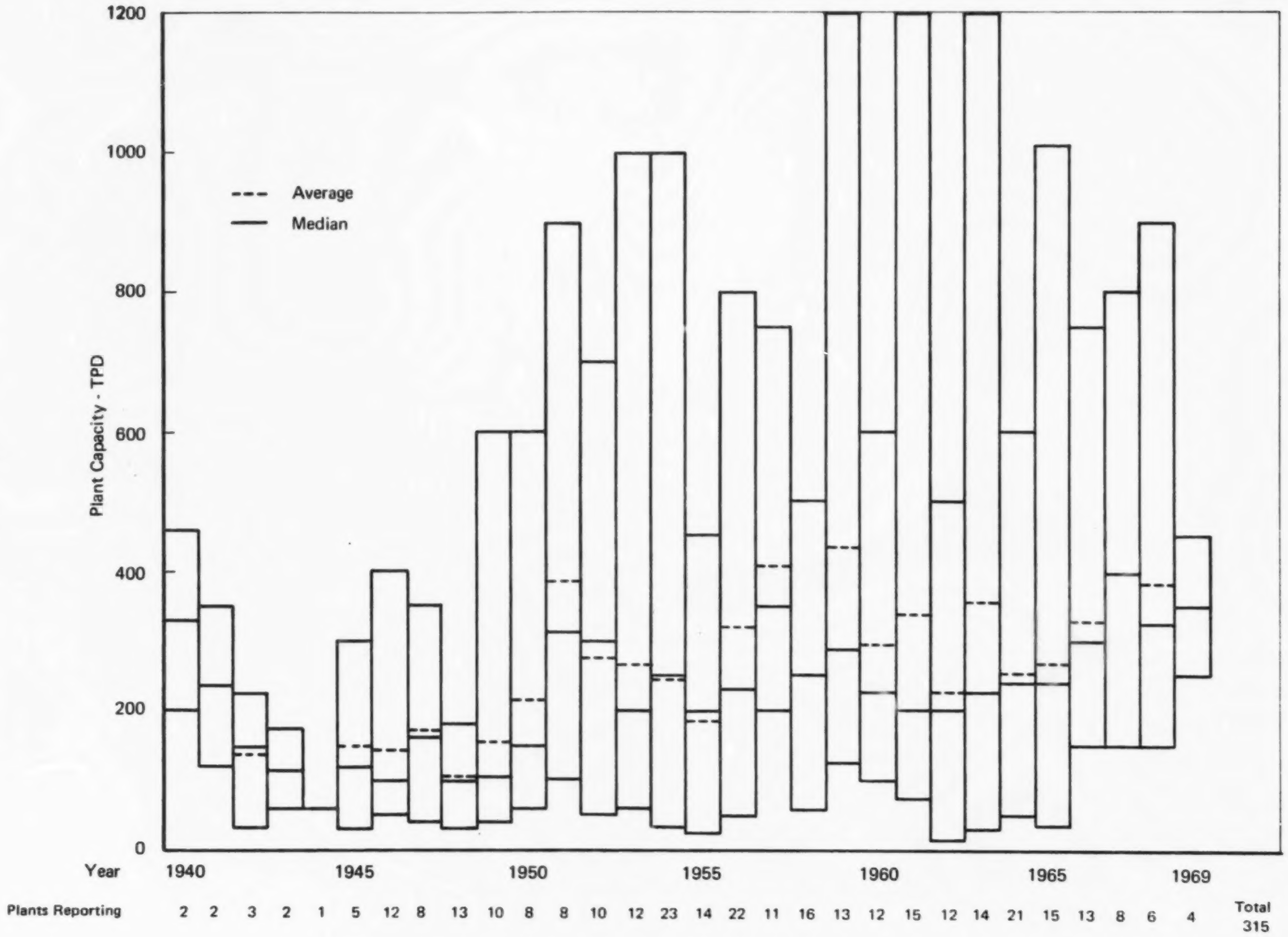


FIGURE I–2 RANGE OF PLANT CAPACITIES : NEW, REBUILT, AND ADDITIONS

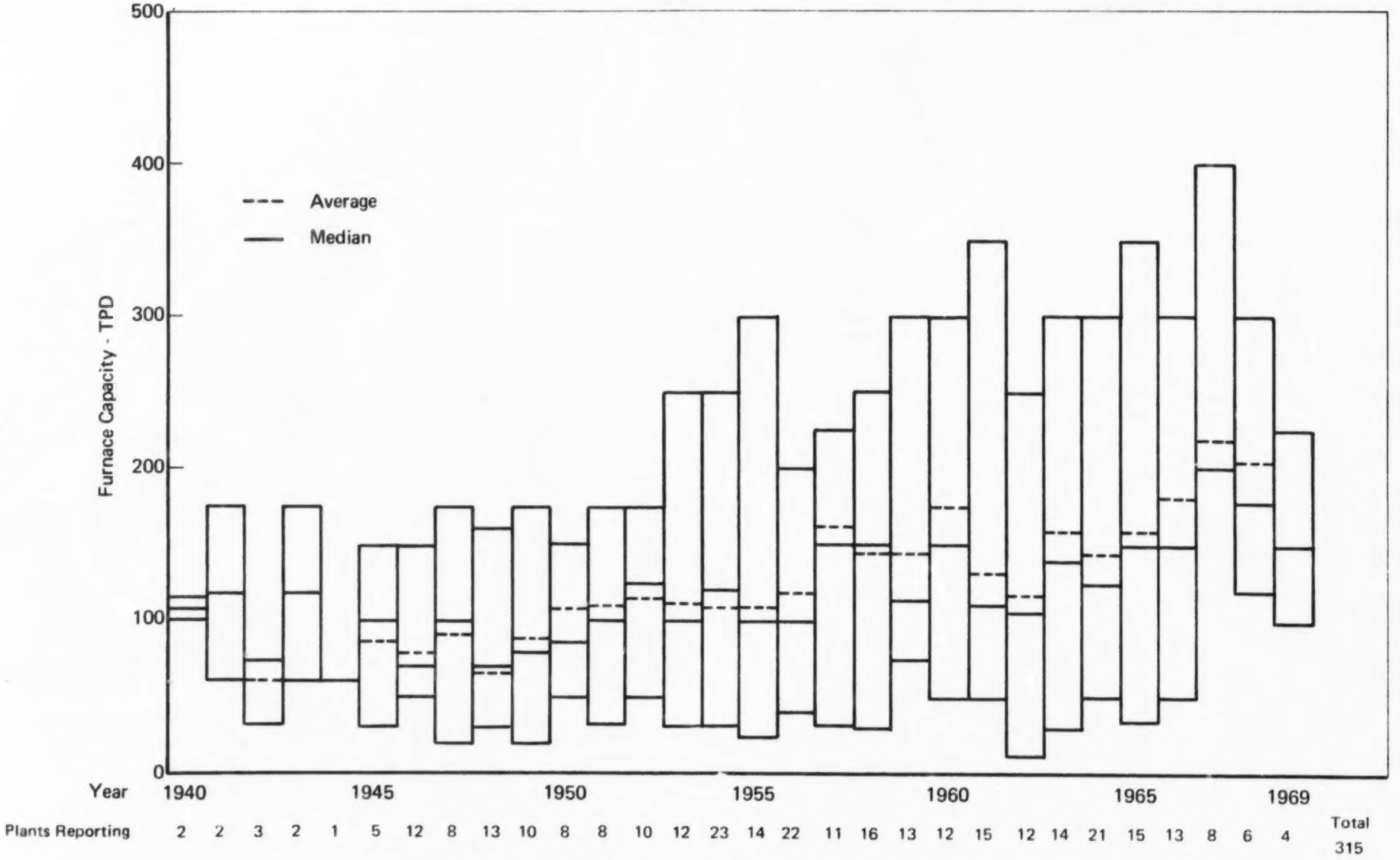


FIGURE I–3 RANGE OF FURNACE CAPACITIES : NEW, REBUILT, ADDITIONS TO EXISTING PLANTS

Figure I-4 shows the predominance of the two-furnace plants to assure availability. Clearly, however, if the total plant capacity is in excess of about 600 tons per day, multiple furnace installations have been selected as an alternative to increasing the furnace size above 300 tons per day.

c. Furnace Type

Figure I-5 shows the emergence and growth of continuous furnace designs. It is clear from this graph that an increasing number of plants are being built for continuous feed. Figure I-6 shows this in still more striking fashion and indicates the trends in furnace type as characterized by grate system. It can be seen that the existing capacity is primarily composed of batch units, the majority of which were built in the 1950's. From an air pollution standpoint, the shift toward continuous units (and the closing of the older batch units – Table I-1) is advantageous. As will be shown in Chapter VI, the batch units have considerably higher combustible pollutant loadings, although total particulate emissions tend to be slightly lower than the continuous plants.

d. Air Pollution Systems

Figure I-7 shows the shifts in the choice of primary air pollution control equipment among incineration plants. The primary incineration control equipment is that having the greatest effectiveness. In many plants, a combination of sprays and wet-bottom expansion chambers are used, followed by a higher efficiency system, such as close-spaced wetted baffles, or a high-energy scrubber. These combinations are not shown on Figure I-7, as, in general, the most efficient system characterizes the plant stack emission characteristics.

There is a distinct trend away from the dry expansion chamber systems (and "none") toward increased use of cyclones, close-spaced wetted baffles, and scrubbers. This trend undoubtedly reflects the increased public attention to air pollution and is expected to continue in the future. Indeed, it is doubtful that more than one or two of the plants built in the future will be equipped with low-efficiency particulate collection devices.

e. Combustion Parameters

(1) Grate Burning Rates (lb burned/sq ft of grate surface per hour)

The design grate burning rates for a variety of different stoker types were presented in some detail by Stephenson et al.[1] From the questionnaire described below, additional data were solicited (some of which duplicate Stephenson's results). Calculated grate burning rates are presented in Table I-2. It can be seen that, in general, the batch-fired units have a lower design burning rate than the continuous units.

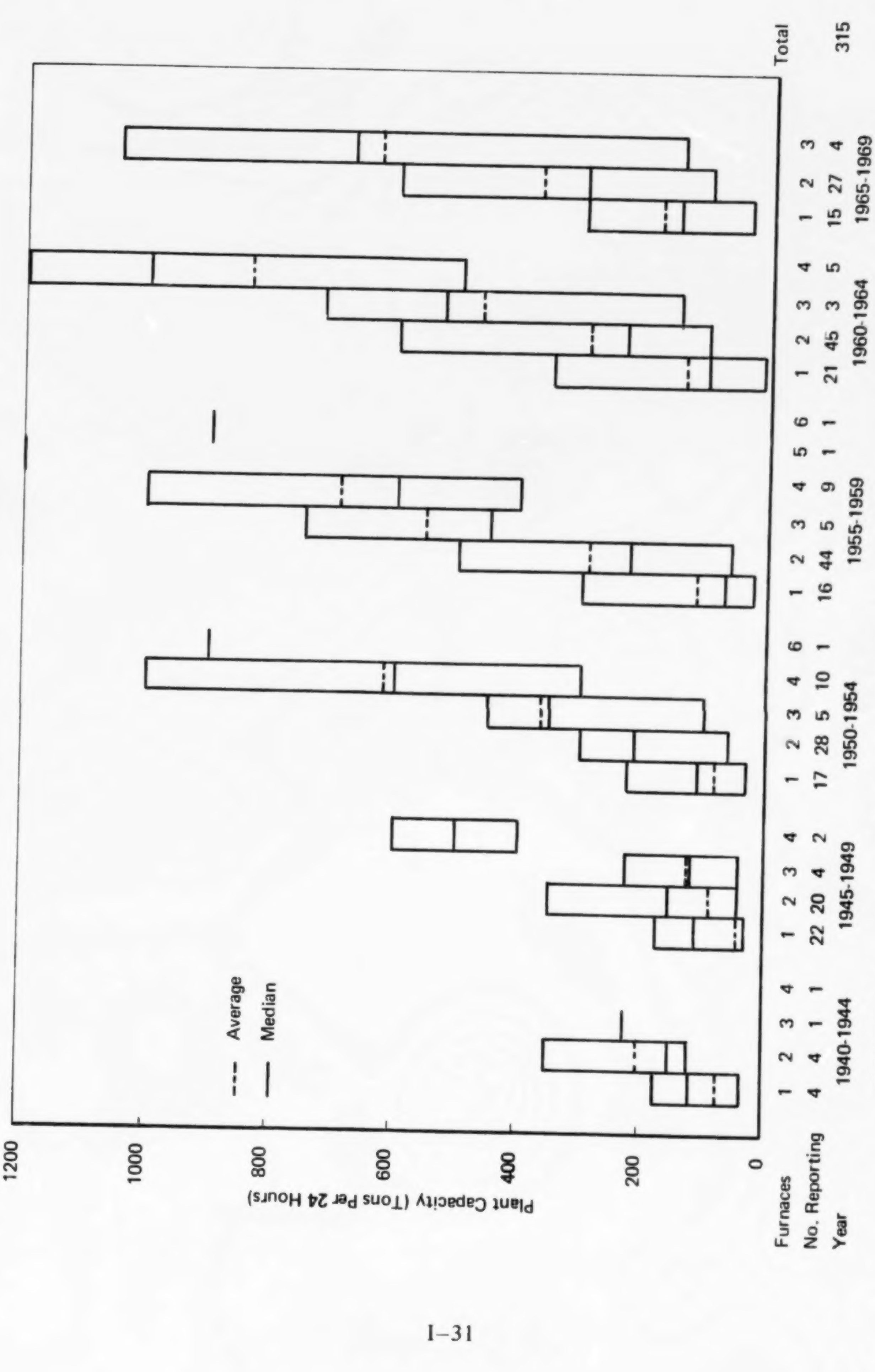


FIGURE I–4 NUMBER OF FURNACES INSTALLED PER YEAR VERSUS PLANT CAPACITY

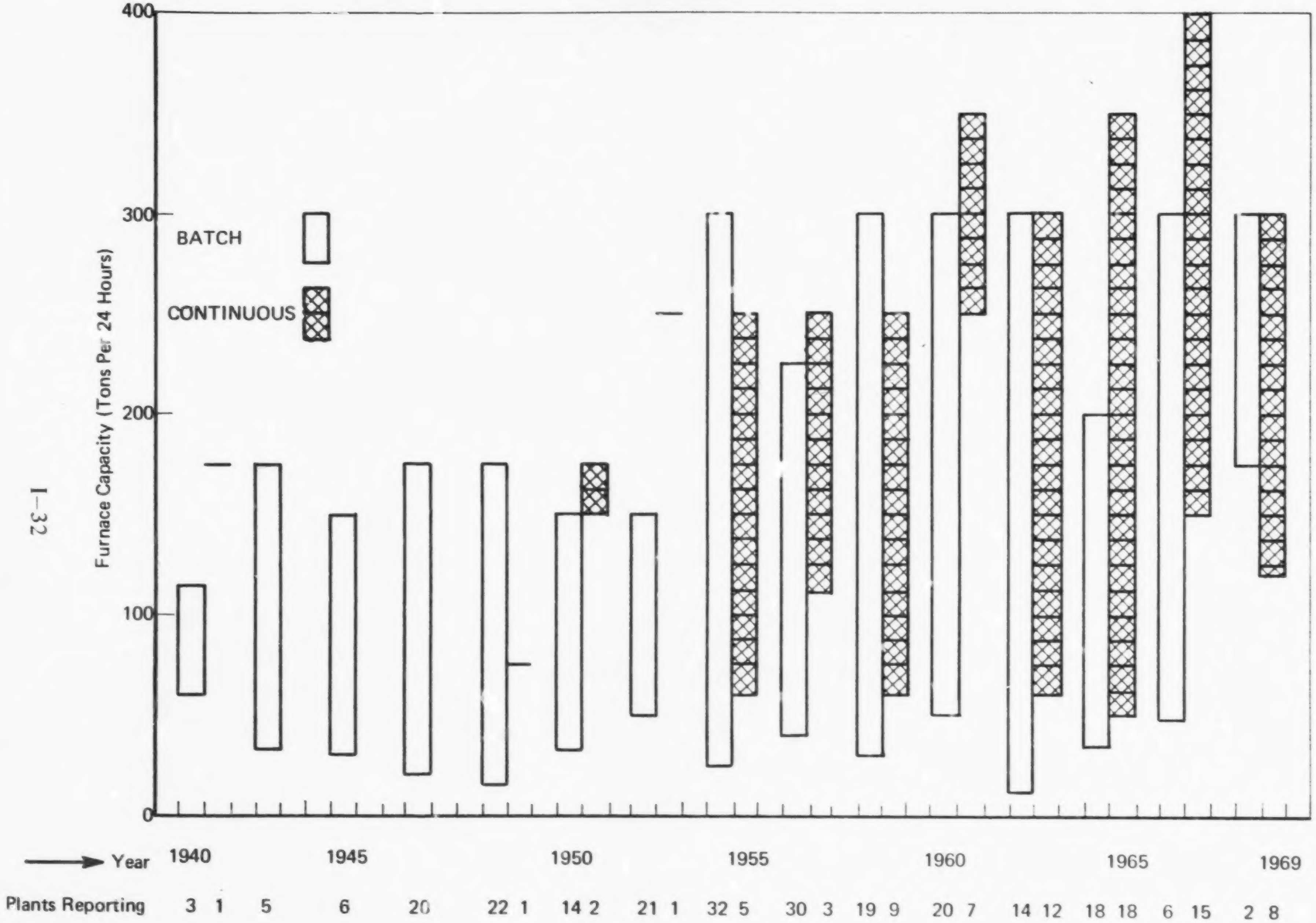
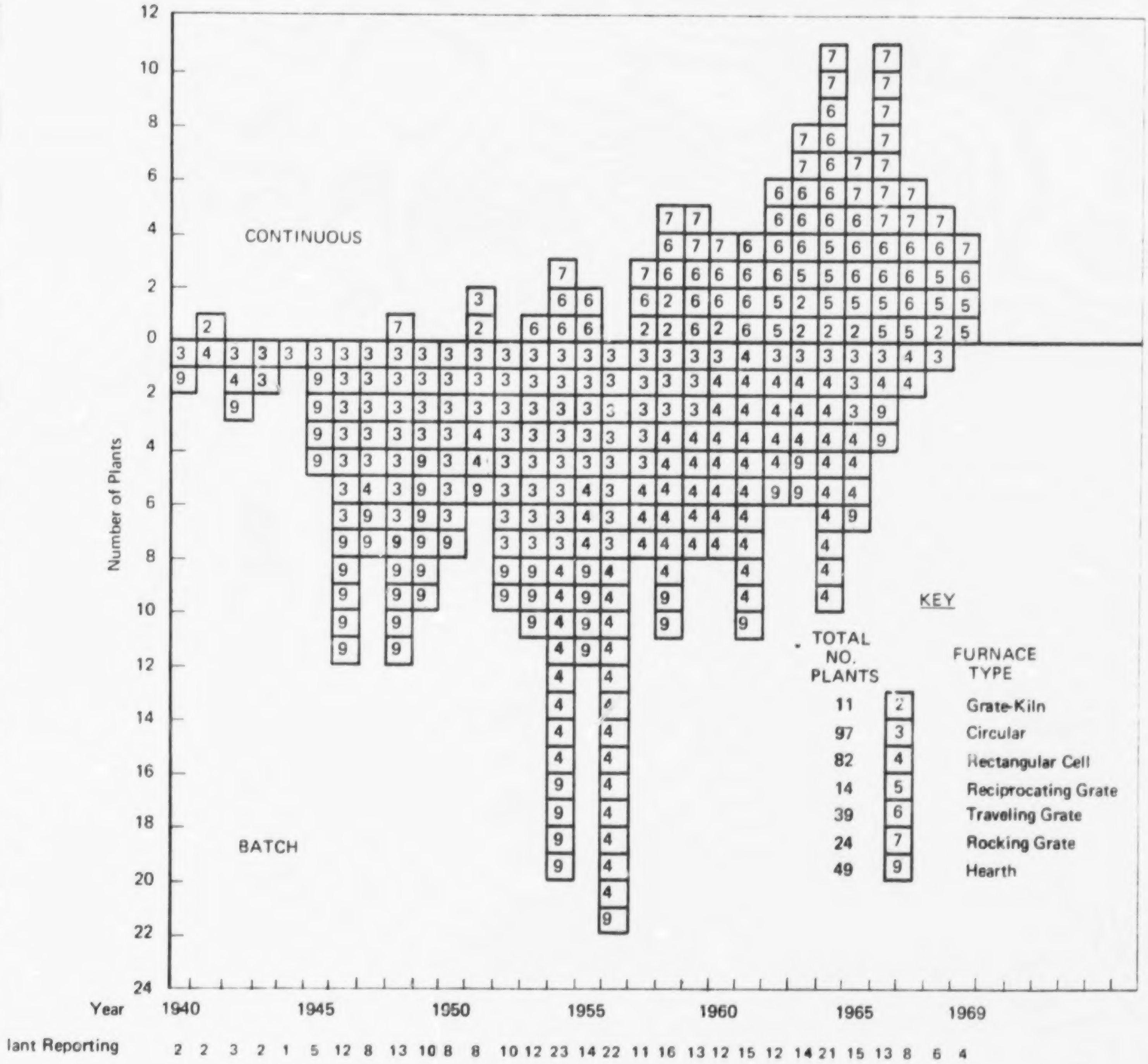


FIGURE I–5 RANGE OF FURNACE CAPACITIES BATCH AND CONTINUOUS



*Source: Table I-1

FIGURE I-6 STOKER TYPE AND FURNACE FEED

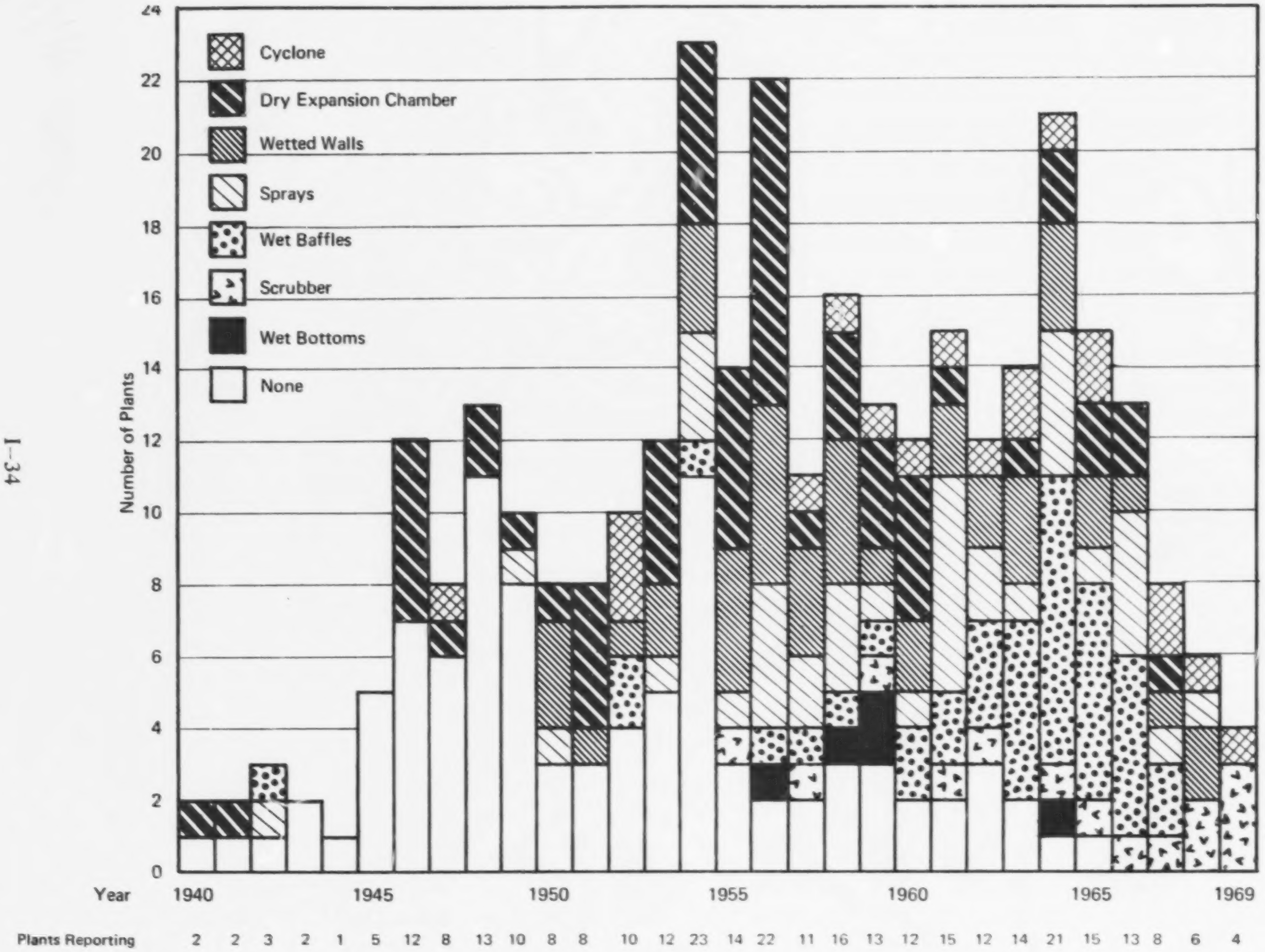


FIGURE I–7 PRIMARY AIR POLLUTION CONTROL EQUIPMENT

TABLE I-2

GRATE BURNING RATES

(lbs refuse/sq ft of grate surface per hour)

Stoker Type	Feed	Year	No. Reporting	Max.	Min.	Median	Average	Standard Deviation
I. Design Values[1]								
Manual	Batch	1946–1958	8	91	37.7	47/67	59	–
Circular	Batch	1945–1965	59	110	45.4	84	83.3	–
		1961–1965	2	70	70	–	70	–
Rocking	Batch	1949–U.C.[a]	37	71	32.4	57.5	56.8	–
		1961–1965	10	60	43	57/57.5	56.0	–
Rocking	Contin.	1963–U.C.	9	67.5	50	58	58.7	–
Traveling	Contin.	1954–U.C.	23	70	55.5	65	64.3	–
		1961–U.C.	15	70	55.5	65	63.7	–
Reciprocating	Batch	1959–1965	11	87	35	57	57	–
		1961–1965	9	60	35	57	53.6	–
Reciprocating	Contin.	1963–U.C.	8	75	55.5	60	62.9	–
Oscillating	Batch	1958–1964	2	69.5	60	–	64.8	–
		1961–1964	1	–	–	69.5	–	–
II. Actual Values*[b]								
Circular	Batch	–	17	–	–	–	69.4	39.6
Rectangular Cell	Batch	–	15	–	–	–	76.8	52.7
Continuous	Contin.	–	34	–	–	–	59.0	13.0
Hearth (manual)	Batch	–	4	–	–	–	64.3	27.9

---

a. Refers to plants under construction at the time Stephenson et. al. were preparing their paper (1966).

b. Based on questionnaire responses.

In the second part of the table (values based on operating practices), this trend is confirmed. The large standard deviation for the batch units in this second part of the table is also of significance. It is probably true that the wide range of burning rates reflects substantial differences in operating practices, rather than differences in ease of refuse combustion, unusual furnace configurations, or special stoking mechanisms. Thus these data provide another indication of the influence of the plant operator in controlling residue quality. Undoubtedly, those plants operating at very high grate burning rates are producing inferior, relatively unburned residue, whereas the lower rates reflect long burning times, probably associated with high residue quality.

It is also of interest to note that the standard deviation for continuous units, in the second part of the table, is relatively small compared to the batch units. Considering the diversity of plants included in this category, this probably reflects an improving technological basis for design. The values for continuous units (about 60 lb/sq ft/hr) also may indicate the optimum burning rate for units of this type. It has been envisioned, however, that waterwall boiler construction will permit much higher burning rates, thus offering the promise of improved combustion performance with lower capital investments.

(2) Volumetric Burning Rates An important characteristic of a combustion system is the heat release rate per cubic foot of furnace volume. Although much of the heat release actually takes place on the grates in a relatively small fraction of the furnace volume, volumetric burning rates provide a useful measure of the overall combustion intensity within furnace systems. Table I-3 shows calculated values of volumetric burning rates for various furnace types where the chamber volume used for calculation was that of the primary chamber volume, the secondary chamber volume and the combined volume. These data were developed from the questionnaire returns, and may contain errors, as a result. It has been assumed that for these calculations, the total primary and secondary chamber volumes are available for combustion (i.e., no spray quenching occurs within either chamber).

As in the case of grate burning rate, it can be seen that significant differences exist between batch and continuous units. However, the volumetric heat release is much higher for batch feed systems as compared to continuous feed systems. Considering the high heat release rate which occurs upon charging batch units, their smaller combustion space may account, in part, for the high combustible pollutant emission coincident with charging. It should be noted that if the combined primary and secondary chamber volumes are considered, the average volumetric heat release rate for continuous and batch units approaches the same value. However, since batch units operate under unsteady burning conditions, the meaning of the term "average heat release rate" is somewhat uncertain. Upon charging, for example, the instantaneous volumetric heat release rate of a batch unit is very high; after burn-down, it is quite low.

TABLE I-3

VOLUMETRIC BURNING RATES
(thousands of Btu/cu ft combustion volume per hour)

I. DESIGN VALUES[1]

Year	No. Reporting	Maximum	Minimum	Median
1950	1	–	–	38.0
1954	1	–	–	26.3
1956	2	50	20	–
1958	1	–	–	22.6
1959	2	28.8	20.7	–
1960	1	–	–	28.5
1962	1	–	–	25.0
1963	2	36.5	18.5	–
1964	9	36.0	10.0	19.2
1965	6	35.8	4.2	18.3/30.4
Under Construction in 1966	8	25.0	14.0	17.0/17.3

II. ACTUAL VALUES[a]

		Average	Standard Deviation
A. Based on Primary Chamber Volume			
1. Circular	16	31.3	16.7
2. Rectangular	13	37.8	45.0
3. Continuous	22	18.6	7.1
4. Hearth	4	43.3	63.6
B. Based on Secondary Chamber Volume			
1. Circular	6	29.2	20.9
2. Rectangular	10	19.6	8.0
3. Continuous	15	22.6	10.6
4. Hearth	3	35.6	21.7
C. Based on Combined Volume (primary plus secondary)			
1. Circular	6	11.0	4.1
2. Rectangular	10	11.1	3.6
3. Continuous	15	9.3	2.6
4. Hearth	3	16.2	14.3
D. All Furnace Types			
1. Primary	55	28.6	29.2
2. Secondary	35	23.3	14.0
3. Combined	34	10.8	5.0

---

a. Based on Questionnaire Responses (assumed 4450 Btu/lb Refuse).

(3) Underfire/Overfire Air Ratio The underfire/overfire air ratio is an important parameter in characterizing furnace combustion and air pollutant emission. Underfire air rate affects grate burning rates, provides grate cooling, and is importantly related to particulate carryover by the suspension of fine ash materials. Overfire air is important in obtaining complete burnout of volatilized combustible material, if introduced at relatively high velocities to stimulate mixing.

The increasing use of higher overfire air rates can be seen in Table I-4. It must be recognized, however, that these data reflect design information; operating conditions are often quite different. Information which would permit calculation of this ratio was requested directly and indirectly in the questionnaire, but no satisfactory data were returned.

C. CURRENT OPERATING PRACTICES

Although the efforts of the designer are important in achieving good incineration, the ultimate deciding factor is the operator. In many plants, for example, provision is made for variation of underfire air rates along the grate, but the dampers are all fully opened. Often, such deviations from the original design reflect local problems, such as the rapidly increasing disposal requirement without a corresponding increase in incinerator capacity. However, improper operation of well-designed plants is also common. In general, however, the operators of U.S. incinerators are interested in their work; and they attempt to operate the unit properly, within the limitations placed upon them by their municipalities or the equipment.

Sections 1.-12. present the results of analysis of data received in response to a questionnaire designed to provide an engineering data base on plant operating problems and practices. Although these data may not be representative of the entire incinerator industry, they do represent, in summarized form, a cross-section of new and old plants, both batch and continuous feed, throughout the country.

It was felt that such operating data should come from the incinerator operators themselves. Although it would have been desirable to make a personal visit to every incinerator, this was not feasible. As a result, a questionnaire was prepared, incorporating the suggestions of a number of local incinerator operators. The questionnaire form finally used is shown in Appendix D.

In view of the large number of questionnaires now being sent to incinerators by state and federal agencies and private companies, special efforts were made to design attractive, easy-to-fill-out forms, providing "yes-no" answers where possible rather than requiring a written response. Generalized drawings were made of seven separate basic incinerator designs, with over-printing in red to indicate

TABLE I-4

OVERFIRE AND UNDERFIRE AIR DISTRIBUTION

(as a percent of total combustion air flow)

	Number Reporting	% Underfire Air			% Overfire Air		
		Maximum	Median	Minimum	Maximum	Median	Minimum
1945–1950	0						
1951–1955	5	89%	80%	62%	38%	20%	11%
1956–1960	11	100[a]	67	33	67	33	0
1961–1966	27[c]	100[b]	65	33	67	35	0

---

a. One plant reports provision for variation from 100 percent underfire to 33 percent underfire and 67 percent overfire; another from 100 percent underfire to 67 percent underfire and 33 percent overfire.

b. One plant reports provision for variation from 100 percent underfire to 33 percent underfire and 67 percent overfire; another from 100 percent underfire to 50 percent underfire and 50 percent overfire.

c. 46 percent underfire and 54 percent overfire reported for one rubbish furnace - not included in table.

where answers were required. Although only one of the seven basic designs sent out is included in Appendix D, every questionnaire included a full set of seven.

Based on the incinerator listings in References 1 and 2 and other sources,[3,4] questionnaires were mailed to 326 incinerators over the period March 19-28, 1969. By mid-June, 120 responses had been received (36.8% of those contacted). Over this time period, two follow-up letters were sent out. The following paragraphs present the results of the questionnaire solicitation and a summary analysis of their meaning.

The following data will often be given in terms of an average and a standard deviation. The standard deviation values shown are in the same units as the average, *not* as a percent of the average.

1. Incineration Population Analyzed

Of the 120 plants responding to the questionnaire, 31 (or 25.8%) were shut-down, two responded too incompletely for evaluation, and 87 were still in operation. They were distributed as follows: grate-kiln – (3), circular batch-feed – (23), rectangular batch-feed – (17), continuous-feed systems – (39), and hearth systems – (5). This distribution of incinerator types is, by chance, quite comparable to the total active incinerator population. It is likely that the plants represented in the questionnaire returns are staffed by plant superintendents with more than average interest in their plants and in contributing to improved incineration technology. In reviewing the questionnaires, it is clear that a number of the operators spent several hours in careful collection of data and in thoughtful preparation of responses. The high response rate and the detail included on many of the returns is a credit to the incineration community.

2. Age of Plants Analyzed and Anticipated Plant Life

The 87 replies for operating plants gave an unweighed average year of construction of the plant as 1956. From Question 1, the operator's estimate of the average life of an incinerator plant was 25.73 years, based on 15 replies. Two replies were in the 35-40 year range; seven in the 27-30 year range; four in the 18-22 year range; and two in the 13-15 year range. The last two values are probably low, since they represent the time before rebuilding or reconstruction.

TABLE I-5

ESTIMATED REFUSE COMPOSITION BY PERCENT OF WEIGHT AND VOLUME

	Plants Reporting	Average
Combustibles by Volume	20	56.30%
Combustibles by Weight	25	49.36
Noncombustibles by Volume	22	11.09
Noncombustibles by Weight	25	11.96
Garbage by Volume	23	25.42
Garbage by Weight	25	27.36
Yard Waste by Volume	21	4.16
Yard Waste by Weight	25	8.24
Other by Volume	21	2.57
Other by Weight	25	3.20

3. Refuse Characteristics

Of 87 replies, 89% of those answering indicated that refuse quantities were increasing. Only two reported decreases. The majority of the incinerators were handling residential refuse, estimated at 75% of their feed (18% standard deviation). Response on population served was quite variable, averaging 131,000 persons with a standard deviation of 143,000. On the basis of installed capacity [tons per 24-hr day (TPD)] per 1,000 persons served, the average was 4.37 with a standard deviation of 4.23. The scatter diminished, however, when the ratio was calculated on the basis of tons burned daily, rather than the installed capacity. The average for this quantity was three tons burned per day per 1,000 persons, with a standard deviation of 1.9. Three tons per day per 1,000 persons served corresponds to 6 pounds per person per day (ppd) for the overall incineration rate or 4.5 ppd on the basis of 75% residential refuse. This is in agreement with data presented in Table IV-1 of Chapter IV.

4. Methods of Performance Evaluation and Control

Tables I-6 and I-7 show the response to questions dealing with judgment of plant performance and control methods. It can be seen that the primary indicators of performance are temperature and residue quality. Only 6% of the replies indicated air pollution considerations as a control parameter. In general, temperatures were measured in the secondary chamber.

Table I-8 shows refuse feed rate and combustion air to be the primary system variables used to meet performance objectives. It is significant, however, that no satisfactory responses were received defining the quantities of air used, percent excess air, overfire to underfire air ratio or other quantitative measures of the magnitude of these parameters.

Table I-9 indicates the views of the plant operators regarding equipment that would improve their operation. It is interesting to note that only three of the 53 responding felt their unit did not need improvement.

The answers to questions regarding slagging problems were generally imprecise and varied too widely to suggest any trends. As with other questions regarding refractories and related problems, the answers varied so widely as to render the results of little value other than to point out the need for research in this area to provide reliable, trouble-free refractory materials and designs.

Table I-10 shows the methods by which air pollution control performance was evaluated. Only four of the 54 responses indicated that complaints from nearby residents was their most meaningful measure of success in air pollution control. Almost all of the operators at the plants visited in the course of this program, however, suggested "complaints" as the ultimate judgment upon the effectiveness of their air pollution abatement efforts.

5. APC System Evaluation

Table I-11 indicates the distribution of air pollution control (APC) types among the plants from which replies were received and general approval or disapproval by the operators of system performance. Although the sampling is limited, it appears that cyclones, scrubbers, and close-spaced wet baffles are received with approval, whereas dry expansion chambers, simple sprays, and wet bottom expansion chambers are poorly received. Surprisingly, simple wetted wall baffles were relatively well accepted, although tests have shown (see Chapter VII, Section B) that these APC systems are relatively ineffective.

TABLE I-6

METHODS OF JUDGING PLANT PERFORMANCE
Number of Replies = 78

Method	No. Reporting Each Method	% Reporting Each Method
Temperature	74	94.87
Residue Quality	58	74.36
Other Methods		
• Draft	2	2.56
• Flame Appearance	3	3.85
• Smoke Trace from Chimney	5	6.41
• Thickness of Fire Bed	1	1.28

TABLE I-7

LOCATIONS WHERE GAS TEMPERATURE IS MEASURED
Number Reporting = 55

Location of Thermocouple	No. Using	% of Those Reporting
Primary Combustion Chamber	14	25.45
End of Grates	15	27.27
Combustion Chamber (sec. chamb.)	27	49.09
Stack	4	7.27
Others	3	5.45

TABLE I-8

ADJUSTMENTS USED TO CONTROL INCINERATOR BURNING

Number Reporting on Adjustment = 79 (90% response)

Method	No. Using Method	% of Those Reporting Using Method
Vary Feed	73	92.41
Vary Underfire Air	55	69.62
Vary Overfire Air	67	84.81
Other	17	21.52
None	1	1.27

Other Consists of:	Responses
1. Vary Stack Dampers	1
2. Mixing Refuse	7
3. Maintain Temperature	1
4. Vary Grate Speed of Kiln	2
5. Induced Draft Control	2
6. Vary Burning Time	3
7. Stoking	1

TABLE I-9

OPERATORS' OPINION OF EQUIPMENT CHANGES WHICH WOULD IMPROVE THEIR OPERATION

Number of Replies = 53 (60% response)

Equipment Changes	No. Responding	% Responding
Refuse Storage & Treatment	8	15.1
Feed Method	7	13.2
Underfire & Overfire Air	7	13.2
Grates	13	24.5
Residue Treatment	6	11.3
APC & Gas Cooling Equipment	8	15.2
I. D. Fan	2	3.8
Expansion of Unit	2	3.8
Other	8	15.2
None	2	3.8

TABLE I-10

METHODS OF JUDGING PERFORMANCE OF AIR POLLUTION CONTROL EQUIPMENT

Number of Replies = 54 (61% response)

Method of Judging Performance	No.	%
By Eye	29	53.7
Gas Sample	6	11.1
Smoke Readings	7	13.0
Amount of Fly Ash Caught in APC Equipment	9	16.7
Neighbors' Complaints and Fly Ash in Area	4	7.4
Periodic APC Tests	2	3.7
Other	4	7.4

TABLE I-11

AIR POLLUTION CONTROL TYPE AND SATISFACTION

	Responding		Approval with APC System			
	No.	%	No Ans.	Yes	No	N/A
Cyclone	6	6.89	1	4	1	–
Dry Expansion Chamber	15	17.24	5	3	7	–
Sprays	6	6.89	3	2	1	–
Scrubber	8	9.19	0	6	2	–
Wet Bottom Expansion Chamber	4	4.59	1	1	2	–
Wet Baffles (close spaced)	23	26.43	2	17	4	–
Wet Walls	9	10.34	0	7	2	–
None	16	18.38	2	–	–	14

In response to Question 21, which asked about planned improvements, 38.8% of the 67 replies indicated that APC and gas cooling equipment modifications were planned in the near future. This response was over five times more frequent than any other concerning plant improvement plans.

APC system repair frequency was generally good. The nine plants reporting on this question indicated repair at a one-year frequency and replacement at a thirteen-year frequency (longer than any other incinerator subsystem noted on the questionnaires).

6. Operating Personnel

Based on 67 replies, the average employee at an incinerator has been with the plant for 8.85 years. Twenty-two of these plants indicated a training program averaging approximately four months. Fifty-eight plants reported no training program. Based on responses from 73 plants, the average foreman is in charge of approximately eight men. Although employee tenure appears long, 31 of 74 responding plants indicated difficulty in obtaining new men; 32 said new men could be hired with fair ease; and 11 could readily find new employees.

7. Feed Density

The traveling grate acts as a conveyor belt, and as such, the characteristics of refuse movement are more predictable than for rocking or reciprocating grates. Table I-12 indicates the apparent feed density, percent volume reduction, and average residence time determined, using reported data on height of the feed arch, estimates of refuse bed depth, and grate speed. The indicated average refuse feed density of 14 lb per cubic foot (378 lb per cu yd) is comparable to that reported for refuse density in the pit. The 18% residual volume (82% volume reduction) seems to be a reasonable estimate of the performance to be expected from these plants.

8. Grate Residence Time

a. Continuous Systems

Because of the conveyor belt action of the traveling grate, grate residence time can be readily calculated from grate speed and length. Although the calculated grate residence time values (Table I-12) were somewhat variable, approximately one hour of residence time on the grate appears necessary to produce residue quality considered acceptable by the operators. This value is consistent with averages developed for other grate systems as reported by grate vendors and consulting engineering firms.

TABLE I-12

TRAVELING GRATE UNITS – HEIGHT AT FEED ARCH, APPARENT FEED DENSITY APPARENT VOLUME REDUCTION, & RESIDENCE TIME

Code No.	Grate Type	Height feed arch	Apparent Density lb/ft ^{3}	Apparent Residual Vol. as % of feed	Residence time (min.)
251-22	1-Trav. Grate	4	6.5	25.0	29.6
151-23	"	4	10.6	18.7	30.0
67-13	"	3.83	5.0	9.8	30.0
178-15	2-Trav. Grate	4	7.2	15.6	50.0
98-23	"	4	12.7	11.1	64.3
700-23	"	4	14.4	20.0	73.0
56-23	"	4	15.5	20.5	49.5
116-23	"	3	20.6	29.1	80.4
117-23	"	4	15.5	12.3	91.4
48-23	"	4	14.7	22.7	82.9
136-23	"	4	14.7	19.6	79.5
201-24	"	4	10.4	12.5	52.8
127-24	"	4	20.8	16.6	57.6
134-24	"	4	20.8	16.6	57.6
143-24	"	4	20.8	16.6	57.6
198-13	3-Trav. Grate	3	13.8	18.4	54.1
711-55	"	4	–	–	–
	Average	3.9	14.0	17.8	58.8
	Standard Deviation	0.33	5.1	5.1	19.1

b. Batch Systems

Air pollution and a number of other operating problems associated with batch fed units are related to the charging operation (see Chapter V). Figure I-8 shows, as a histogram for cylindrical and rectangular units, the various responses to questions regarding charging frequencies. Although the responses were widely variable, they appear to concentrate in the range of 5-10 charges per hour.

Grate dumping frequency for rectangular and circular batch-fired units is shown as a histogram in Figure I-9. Again, considerable variability exists. It should be noted that dumping and charging rates were developed, assuming operation on a 24-hr-per-day basis.

Data on charging and dumping frequency for batch-feed units and on the residence time for continuous-feed traveling grate units are summarized in Table I-13. It can be seen that the batch-feed units require a considerably longer grate residence time than continuous-feed units. Once again, the considerable variation indicated by the standard deviation shows the influence of the operator on residence time, and thus on residue quality.

9. Operating Factors

Based on 87 replies, the average plant had a scheduled availability corresponding to an operating factor of 56.6% (based on 24-hr operation, with a seven-day week at the *rated* capacity). The standard deviation was 27.46%. The average unscheduled downtime due to maintenance problems or other causative factors was 7.38% (5.13% standard deviation). Thus, the average use was 52.4% of the 24-hr, seven-day operation. A number of plants, however, reported that less than the rated capacity was charged, so that, based on the *rated* capacity, the average incinerator operating factor is 43.25% (30.38% standard deviation). This large variation probably reflects the different operating schedules (1-, 2-, or 3-shift operation).

10. Incineration Temperatures

Table I-14 shows reported values for flue gas temperatures in various parts of the furnaces, according to furnace type. Although some variability is shown, the reported values are quite similar. In all cases, the temperatures shown are more than needed to assure complete burnout of all combustible air pollutants. The fact that such materials do appear at substantial concentrations in stack effluents indicates the unreliability of the reported measurements as representative averages. It is clear, from other data,[5] that stratification occurs in furnaces, permitting substantial amounts of colder gas to pass through the system.

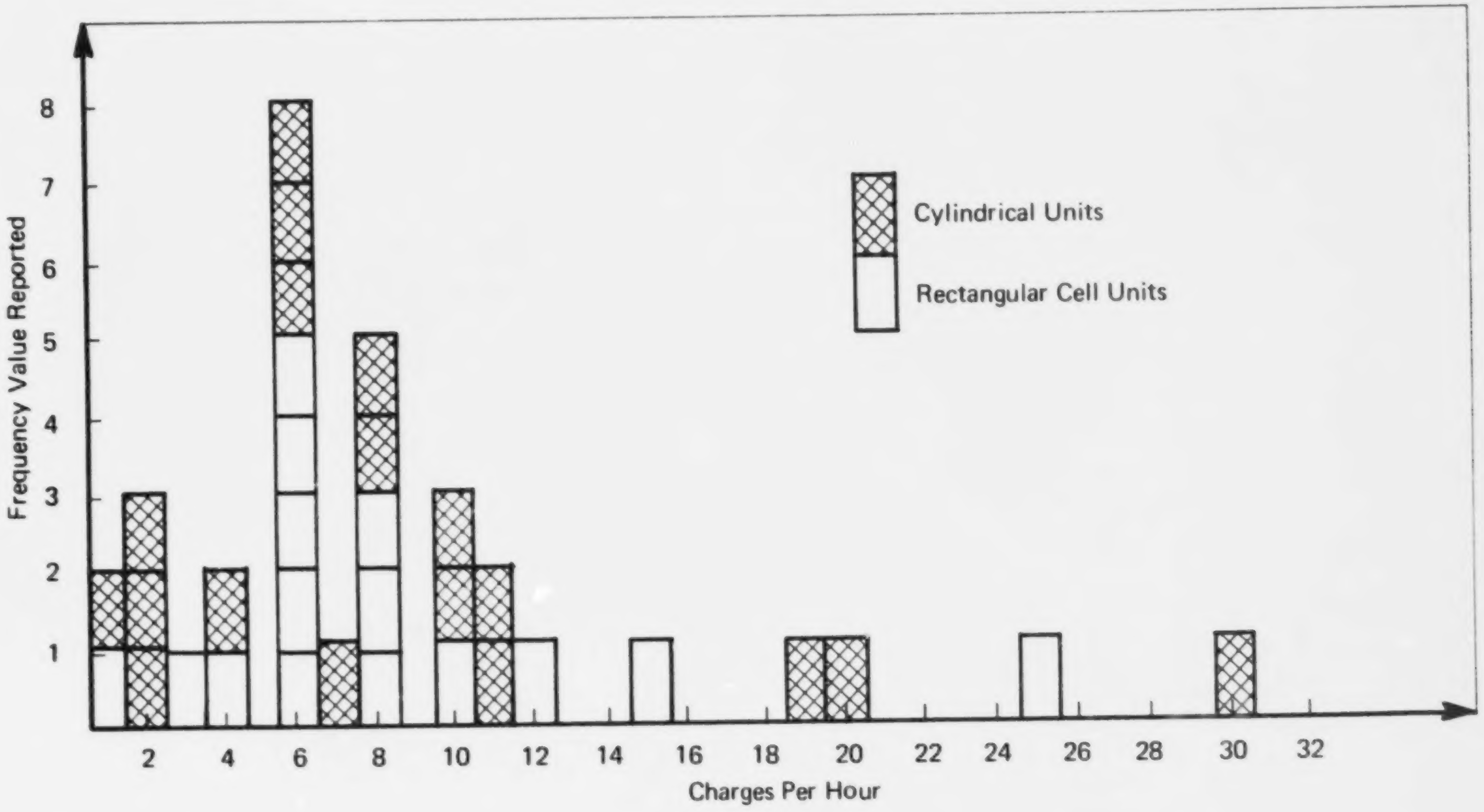


FIGURE I–8 FREQUENCY OF OCCURRENCE OF CHARGING RATES, BATCH FEED INCINERATION SYSTEMS

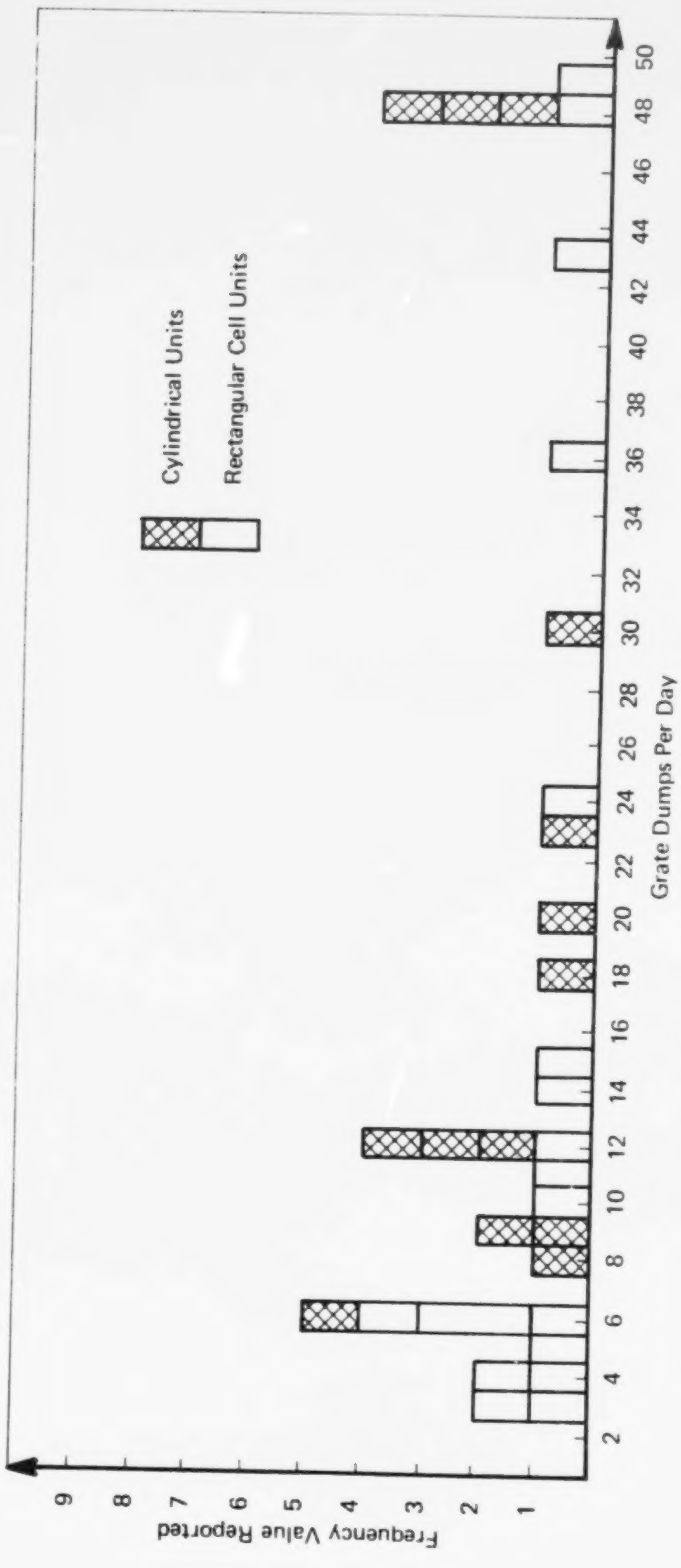


FIGURE I–9 FREQUENCY OF OCCURRENCE OF DUMPING RATES, BATCH FEED UNITS

TABLE I-13

AVERAGE GRATE RESIDENCE TIME

Furnace Type	No. Reporting	Grate Residence Time (min) Average	Grate Residence Time (min) Standard Deviation
Circular Batch	17	116	110
Rectangular Batch	12	103	72
Traveling Grate	19	61	22
Hearth (Manual Stoked)	2	180	85
All Types	50	94	80

TABLE I-14

REPORTED
INCINERATOR TEMPERATURES

	Furnace Type All Units	Grate-Kiln	Circ. Batch	Rect. Batch	Continuous	Hearth
I. Primary Chamber						
a) No. Reporting	63	3	16	14	28	2
b) Average Temp. (°F)	1675	1833	1581	1621	1725	1850
c) Standard Deviation (°F)	218	153	271	223	167	71
II. Secondary Chamber						
a) No. Reporting	17					
b) Average Temp. (°F)	1288					
c) Standard Deviation	394					
III. Stack						
a) No. Reporting	39					
b) Average Temp. (°F)	636					
c) Standard Deviation (°F)	266					

The high standard deviation in the stack temperature reflects, to a large extent, the presence or absence of wet scrubbers or sprays for flue gas conditioning or air pollution control.

11. Combustion Air

Few of the respondents to the questionnaire were able to report the percent excess air for their furnaces. Based on the standard refuse composition presented in Appendix C and the data reported above on primary chamber temperatures, however, a simple energy and material balance can be used to produce estimates of the percent excess air. Based on 63 data points, the average percent excess air calculated by this method was 144%, with a standard deviation of 50%. As mentioned above, however, the stratification evident in many incinerator furnaces[5] suggests that the indicated primary furnace temperatures are too high. The argument that all combustible pollutants would be destroyed (but would be found) at these temperatures strengthens this hypothesis. Since the only mechanism permitted by the analysis to reduce temperature was in this energy balance approach to calculation of combustion air dilution; an unrealistically high temperature results in a low calculated excess air level.

12. Mean Flue Gas Residence Times – Primary Chamber

Using a material and energy balance similar to that described above, the average residence time can be calculated, based on the primary chamber volume and the estimated percent of excess air and rated refuse feed rate. These calculations were carried out for the 45 plants submitting sufficient data to make this calculation. The results are shown in Table I-15.

It is worthy of note that the average residence time of two seconds is more than sufficient based on kinetic data at the indicated temperatures to burn out combustible pollutants. This is an indication of the importance of flue gas mixing in eliminating these air pollutants by combustion.

TABLE I-15

CALCULATED AVERAGE FLUE GAS RESIDENCE TIME (PRIMARY CHAMBER ONLY)

Furnace Type	No. Reporting	Average Gas Residence Time (sec)	
		Average	Standard Deviation
Circular Batch	13	1.69	1.74
Rectangular Batch	12	1.58	1.24
Continuous	17	2.17	0.67
Hearth	2	7.01	9.55
All Units	45	2.05	2.18

D. REFERENCES

1. MUNICIPAL INCINERATOR DESIGN PRACTICES AND TRENDS
   Junius W. Stephenson and Anthony S. Cariero
   1966 National Incinerator Conference.

2. TECHNICAL – ECONOMIC STUDY OF SOLID WASTE DISPOSAL NEEDS AND PRACTICES – VOLUME I – MUNICIPAL INVENTORY
   Combustion Engineering, Inc., November 1, 1967.

3. Personal Communication, Mr. Junius W. Stephenson
   Havens & Emerson.

4. Interviews with a large number of Consulting Engineers, Vendors, Contractors and APC agencies.

5. COMBUSTION PROFILE OF A GRATE-ROTARY KILN INCINERATOR
   P. H. Woodruff and G. P. Larson
   Proceedings of 1968 National Incinerator Conference.

APPENDIX J

INCINERATOR EMISSION DATA

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APPENDIX J

INCINERATOR EMISSION DATA

A. INTRODUCTION

The pollution potential of a municipal incinerator is a complex function of the plant design, the operating practices, and the refuse composition. Although a quantitative relationship between the three independent variables and air pollution should not be anticipated, analysis of data directed toward this end can provide insight into future pollution problems, point out directions for future design efforts, and suggest improved operating practices.

The purpose of this portion of the report is to present data and analyses of the data directed at answering the questions: Why, and to what extent do incinerators pollute the air? The conclusions drawn in answer to these questions rest upon an extensive data base. To indicate the sources and extent of the data base, the scope and results of our efforts are presented in the form of an emission data bank.

Acquisition of a comprehensive data bank was necessary, in order to define the causes and extent of the air pollution problems associated with municipal incineration as it now exists, and to provide a technical basis for emission projections. In these respects, the data-gathering effort was the basis for our entire study. Our resources included:

- Published literature
- USDHEW – National Air Pollution Control Administration (NAPCA)
- USDHEW – Bureau of Solid Waste Management (BSWM)
- Other federal agencies
- Consulting engineers
- Local air pollution control agencies
- Contractors
- Vendors
- Testing companies
- Incinerator sites
- Our questionnaire
- Associations

1. Literature

Several thousand articles pertaining to the subject were identified in the open literature. From these, over 500 references were selected and are listed in the accompanying bibliography (Volume III). It was not intended that all literature relating to refuse incineration be included in this listing, but that only selected and substantial references from specific subject areas would be included:

- Incinerator data (number, location, capacity, and major design characteristics of municipal incinerators in the continental United States and some data from foreign incinerators);
- Amount and composition of air pollutants emitted by municipal incinerators;
- Effect of design and operating parameters on emission;
- Performance characteristics of commercial and developmental air pollution control devices; and
- New concepts of incineration.

The comprehensive literature search conducted for this project covered the years from 1957 to the present (September 1969). In some areas, however, it was useful to review the literature of earlier years; for instance, that which covered emission data and air pollution control equipment performance. Domestic technical and government sources were reviewed as well as foreign technical literature and literature previously collected by Arthur D. Little, Inc., in various technical areas. The most pertinent sources of information were found to be journals, such as *Public Works, The American City, Journal of the Air Pollution Control Association, Brennstoffe-Warme-Kraft;* publications such as the ASME Incinerator Conferences of 1964, 1966, and 1968; meetings of the Air Pollution Control Association, and the American Society of Mechanical Engineers; and indexing and abstracting services in the area of engineering. Many other sources were, of course, searched.

The references in this bibliography have been reviewed for pertinence to the project, and an effort has been made to avoid redundancy, except in cases where it is useful to have confirmation of data.

2. NAPCA

Through visits and correspondence with several NAPCA branches in Cincinnati, the Air Pollution Technical Information Center in Arlington, Virginia, and through correspondence with groups in Washington, D.C., and Durham, North Carolina, considerable amounts of unpublished data, published articles, and advance copies of HEW reports were obtained and made available for our study and use. In consideration of the dynamic nature of air pollution and solid waste technology, the cooperation extended by all NAPCA agencies contacted was invaluable in assuring the timely availability of new data. Of particular importance were the contributions of the Division of Process Control Engineering. Because of their unique role and position, their efforts had substantial impact on the program.

3. Bureau of Solid Waste Management

The assistance given by the Bureau of Solid Waste Management was extremely helpful in connection with the estimation of national refuse quantities and the release of new data on refuse composition and incinerator emissions. Their constructive criticism of the refuse data analysis methodology improved the quality of our results. Of particular importance was the Technical Services Group, which provided comprehensive data on emissions and refuse quantities.

4. Other Federal Agencies

The primary assistance from this resource class was the Bureau of Mines, in connection with their research on the composition of incinerator residue and fly ash.

5. Consulting Engineers

It became obvious from our literature studies and our contacts with incinerator operators that much useful data could be obtained from the consulting engineering community. We are greatly indebted to the following individuals who helped us in this program, as they were a major source of emission data and information concerning various incinerator locations and operating problems.

- Fay, Spofford, & Thorndike, Inc.
- Hayden, Harding, and Buchanon
- Camp, Dresser, & McKee
- Bassett & Kinraide
- Consoer, Townsend & Assoc.
- Black & Veatch
- Havens and Emerson
- Metcalf & Eddy Engineers, Inc.
- Malcolm Pirnie Engineers
- Burns & Roe, Inc.
- Witmer & Ernst
- Whitman Requardt & Assoc.
- Day & Zimmermann
- Leonard S. Wegman Co.
- Charles R. Velzy Assoc., Inc.
- Henry J. Campbell, Jr. & Assoc.
- Greeley & Hansen

We have received excellent cooperation from the engineers working in this field. Aside from any general desire to contribute as professionals, it was generally recognized that substantial improvements can be made in incineration systems, and that new understanding, helpful to them and their clients is needed.

6. Local Air Pollution Control Agencies

We visited or made direct contact with the following local air pollution control agencies:

- Massachusetts Division of Environmental Health
- New York State Division of Air Resources
- Bureau of APC, Allegheny County, Pennsylvania
- The Los Angeles County APC district
- Power Division of the Pasadena, California Water and Power Department
- APC Division, Wayne County, Michigan
- Connecticut State Department of Health
- Department of Natural Resources, Division of Environmental Protection, Madison, Wisconsin
- Illinois APC Board
- Florida Air and Water Pollution Control Commission
- Air Pollution Unit, Ohio Department of Health
- Division of Air Pollution, Texas State Department of Health
- Air Pollution Control Program, New Jersey Department of Health

The majority of these agencies recognized incineration as an important or potentially important air pollution source within their jurisdiction. In general, however, they did not possess emission data on plants within their areas; but they offered help in identifying incinerator sites and in suggesting other sources of information.

7. Contractors and Vendors

Historically, equipment vendors and contractors have had a major role in incinerator design. In consequence, we visited or corresponded with a wide variety of individuals in these categories:

- Morse Boulger Div. of Hagen Ind.
- Nichols Eng. and Research Corp.
- Tynan Incinerator Co.
- American Thermogen
- Pyro Ind.
- Sira Corp.
- Dravo Corp.
- Flynn & Emrich Co.
- Detroit Stoker Co.
- M. H. Detrick Co.
- Von Roll, Inc.
- The H.K. Porter Co. Refractories Div.
- Harnischfeger Corp.
- National Dust Collector Corp.

- Plibrico Co.
- North Jersey Incineration Co.
- Eidal Manuf. Co.
- Concentric Engineering, Inc.
- Metropolitan Waste Conversion, Inc.
- Combustion Engineering, Inc.
- International Boiler Works Co.
- Riley Stoker Corp.
- The Carborundum Co.
- UOP Air Correction Div.
- Chemical Construction
- The Ducon Co.
- Buell Engineering Co.
- American Air Filter Co.
- American Standard, Ind. Process Dept.
- Wheelabrator Corp.
- Peabody Engineering Corp.
- Ferro-Tech Industries, Inc.

The engineers interviewed from these companies were, without exception, helpful and cooperative. Their contributions of data, discussions of design concepts, and operating practices were invaluable.

8. Testing Companies

We contacted a number of companies carrying out incinerator air pollution testing. In many cases, information was withheld, due to the obligation to clear such release with a large number of parties.

Organizations contacted include:

- Wisconsin Chemical and Testing Company
- Betz Labs
- New York University, Research Division
- Harvard Air Cleaning Labs
- GCA Corporation
- Roy F. Weston, Inc.
- Battelle Memorial Institute
- New York Research Corporation
- Pollution Control Division, U.S. Testing Co.
- Traveler's Research

9. Incinerator Sites

During the course of the program, we visited a number of incinerator sites, where we spoke directly with the incinerator superintendent. In almost all cases, we were very well received. The men took time to talk and took a genuine interest in contributing their ideas and expressing their needs. Many of the questionnaires received from these men reflected their sincere desire to improve their art.

We visited incinerators in the following areas:

- Newton, Mass.
- Montreal, Que.
- Wellesley, Mass.
- Lowell, Mass.
- Amsterdam, New York
- New Bedford, Mass.
- Brookline, Mass.
- Boston, Mass.
- Belmont, Mass.
- Watertown, Mass.
- Dedham, Mass.
- Framingham, Mass.
- Providence, R. I.
- New Orleans, La.
- Chicago, Ill. – Medill
- Chicago, Ill. – S. W.
- Chicago, Ill. – Calumet
- Chicago, Ill. (suburban) – Melrose
- Chicago, Ill. (suburban) – Stickney
- Milwaukee, Wis. – Erie St.
- Milwaukee, Wis. – Green Bay Ave.
- Milwaukee, Wis. – Lincoln Ave.
- Milwaukee, Wis. (suburban) – Wawatosa
- Milwaukee, Wis. (suburban) – W. Allis
- Port Washington, Wis.
- Pomona, Calif.

10. Questionnaire

The need for definite information on the incineration process as it is now practiced was obtained through the use of a questionnaire. The details of the questionnaire and the results of the solicitation are described in some detail in Appendix I.

11. Associations

At the start of the program, contact was made with the Incinerator Division of the American Society of Mechanical Engineers. In addition, we took advantage of the membership of several ADL participants in the Institute of Solid Waste – American Public Works Association. These groups contributed through their membership, rather than as an association. The Air Pollution Control Association was very cooperative in providing a considerable number of reprints of its articles.

B. EMISSION DATA BANK

The comprehensive collection of data described above yielded several hundred data elements. These data varied widely in quality; in the completeness with which the plant design and/or operating conditions at the time of the tests were described; in the emission units; and in the degree to which the data could be publicized. In order to provide the most comprehensive data bank possible, all credible data were included. These data include furnace and stack particulate emission levels, concentrations of gaseous pollutants, and, where available, the bulk composition and temperature of the flue gas at the point of the test.

In some cases, supplemental information was available on the plant operating conditions at the time of the test. Such data included refuse compositions, air flows, furnace burning rates, and unusual circumstances (such as shutdown spray systems) in regard to the air pollution control device. These comments were incorporated in the "Remarks" column of Table J-1. In almost all cases, no data on the methods of sampling, CO_2 correction, etc., were associated with the emission data.

The use of consistent emission units was highly desirable. Because of the different emission units used in the past, however, it was felt necessary to present particulate emission data in units of pounds per thousand pounds of flue gas, grains per standard cubic foot, and pounds per ton of refuse. In order to convert between these different emission units, a standard refuse was chosen, as described in Appendix C; and a series of conversion factors were developed, based on this refuse composition. The conversion factors are described in Chapter V. The data in the units originally reported to us are noted with an asterisk. We have included (on the following page) a list of the abbreviations used in the Summary of Incinerator Emission Data.

Much of the data presented below were provided on a confidential basis. This reflects the sensitive nature of these data, particularly where the tests were made some years ago and substantial air pollution abatement improvements have been made in the meantime. Other data represent preliminary information which has not yet been published. As a result of these considerations, none of the plants listed are identified by name; they are given a "Plant Number" instead.

Table J-1 presents the emission data on particulate and carbon monoxide emission. The basic organization of the table is built around the furnace type, as reflected in the grate system used. The table is preceded by an Index, identifying the sheet numbers (in the table) where specific numbered plants can be found. This is provided primarily to assist the reader in finding additional data for plants referenced (by plant number) throughout the remainder of the text. Additional data on nitrogen oxides may be found in Table J-2. The limited data on hydrocarbons, hydrogen chloride, and other species may be found in Chapter V, associated with the development of emission factors for these pollutants.

TABLE J–1

INCINERATOR EMISSION DATA

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST BY	TEST YEAR	FURNACE EMISSIONS lb/Mlb	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/Mlb	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	%CO_2	%CO	%O_2	%H_2O	Temp °F	REMARKS
54	75		Hearth (Batch)	Water spray	1	1951				23 *	119	2.59						300% excess air, refuse 11.1% ash (dry basis); 14,140 lb/hr UF air, 58 ft² grate area
													2.1	0.2	18.3	Dry Basis		Analyses taken from graph in report for period of one charge
													0.9	0.2	19.4			
													4.0	0.9	16.25			
													5.9	0.5	14.0			
													8.5	0.3	11.35			
													7.0	0.3	12.7			
													6.3	0.6	13.6			
													5.6	0.3	14.5			
													5.35	0.1	14.9			
													5.3	0.2	14.9			
													5.0	0.2	15.1			
													4.4	0.2	15.7			
													4.3	0.1	16.0			
													3.6	0.1	16.8			
													3.6	0.1	16.8			
													3.7	0.1	16.4			

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST BY	TEST YEAR	FURNACE EMISSIONS lb/Mlb	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/Mlb	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	%CO_2	%CO	%O_2	% H_2O	Temp °F	REMARKS
83	80		Cylindrical (Batch)	None						.700	.366	7.90*	3.4			37.4	452	
										.434	.229	4.90*	3.5			34.6	450	Modified air distribution
										.895	.474	10.10*	3.2			34.1	467	
84	100		Cylindrical (Batch)	None						.291	.155	3.30*	3.9			23.5	413	Modified air distribution
5	100	1956	Cylindrical (Batch)	Wet scrubber		1956												Test / Ald. mg/scf / NO$_x$ mg/scf
										.424	.220*	4.63	1.9	0	17.2	8.7		Start-up A .04 .8
										.443	.230*	4.90	3.1	0	13.2	20.6		B .05 1.5
										.520	.270*	5.75	1.9	0	14.7	17.5		C .14 2.0
										.578	.330*	6.39	1.9	0	15.1	17.4		D .10 2.8
														0				Burning Garbage E .20 3.2
										.578	.330*	6.33	2.7	0	16.4	18.5		F .30 0.31
							.48	25 *	5.33				7.0	0	10.5	11.7		Start-up A .03 3.2
							1.46	.76 *	16.19				4.3	0	12.6	10.4		C .05 4.4
							2.35	1.22 *	25.99				3.4	.3	15.0	8.9		D .80 5.1
							.71	37 *	7.88				4.2	0	12.9	9.2		Burning Garbage E .72 4.3
4	100	1958	Cylindrical (Batch)	Multiple cyclone 5.2" pressure drop	3		1.41	73 *	15.55									No HC emission was noted for any of the tests
							1.18	62 *	13.21									
										217	.113*	2.40				12.0		Reported cyclone efficiency 84.5%, Ave. CO_2 5.03% (dry basis)
										052	121*	2.57				9.5		
										290	151*	3.21				11.0		
										184	096*	2.10				13.0		
										202	105*	2.24				18.2		% excess air / forced air used
69	100		Cylindrical (Batch)				1.10	581	12.4 *									200 UF Feed - paper, cardboard & tree trimmings
							43	229	4.9 *									240 OF
							91	483	10.3 *									200 UF
							57	304	6.5 *									220 OF
88	125		Cylindrical (Batch)	None						1.578	834	17.80*	4.1			26.5		
85	140		Cylindrical (Batch)	None						1.224	647	13.80*	4.2			11.9	1096	

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST NO.	TEST YEAR	FURNACE EMISSIONS lb/Mlb	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/Mlb	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	CO_2	CO	O_2	H_2O	TEMP °F	REMARKS
52	150	1952	Cylindrical (Batch)	Sprays, cyclones			2 60*	1 34	29 31									Furnace operating at 70% of rated capacity
55	150		Cylindrical (Batch)	Water spray	1	1951				20*	10	2 25						300% excess air, refuse 8% ash (dry basis), 29,500 lb/hr air to cone, 125 ft² grate area
9	150	1953	Cylindrical (Batch)	Wetted metal baffles	4	1955				70*	363	7 89						
										90*	467	10 14						
										51*	264	5 74						
										736*	381	8 29						
							993*	515	11 19									
							690*	358	7 77									
							3 661	1 90 *	40 48									
							2 543	1 32 *	28 12									
										66 *	342	7 44						
										77 *	399	8 68						
										55 *	285	6 20						
										67 *	347	7 55						
8	200	1956	Cylindrical (Batch)	Wet expansion chamber & sprays on single wet baffle & extra roof sprays	4		2 57 *	1 333	28 97									
							2 57 *	1 333	28 97									
										75 *	389	8 45						
										37 *	192	4 17						
29	150	1956	Cylindrical (Batch)	Expansion chamber 12' hi x 22' wide x 47'9" long														APC collected 0 1% of refuse weight as fly ash Probe Cycle
19	150	1952	Cylindrical (Batch)	Small expansion chamber & refractory baffle comprised of 250 3" diameter tubes	5	1964				55 *	29	6 20					900	5 C Notes Average
										55 *	29	6 20					900	5 C E CO_2 for all
										09 *	05	1 01					405	5 B E tests "about 6%"
										32 *	17	3 61					868	5 C S on dry basis.
										34 *	18	3 83					900	5 C "Probe" refers
										41 *	21	4 62					900	5 C to distance in
										41 *	21	4 62					900	5 C E feet from the
										27 *	14	3 04					752	5 B "far wall" of
										18 *	09	2 03					753	5 C S the stack to
										34 *	18	3 83					900	8 C the sampling
										34 *	18	3 83					900	8 C probe. "Cycle"
										92 *	48	10 37					900	8 C E refers to the
										1 65 *	86	18 60					853	8 B S operating status

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	Probe	Cycle	REMARKS
					BY	YEAR	lb/MBtu	[illegible]	[illegible]	lb/MBtu	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
19	150		Cylindrical (Batch)		5	1964				64 •	33	7.22					705	1	C	of the unit
										34 •	18	3.83					705	5	C	during the test
										50 •	26	5.64					710	1	C, B	as follows:
										43 •	22	4.85					710	5	C, B	C = charge
										1.08 •	56	12.18					368	1	CO	D = burndown
										49 •	25	5.52					368	5	CO	CO = cleanout
										57 •	30	6.43					748	1	C	E = end of
										52 •	27	5.86					748	7	C	burnout
										47 •	24	5.30					458	1	C	S = start of
										33 •	17	3.72					458	4	C	burn
										37 •	19	4.17					458	7	C	
										77 •	40	8.86					338	1	CO	
										30 •	16	3.38					338	4	CO	
										54 •	28	6.09					338	7	CO	
										89 •	46	10.03					725	1	C	
										21 •	11	2.37					725	4	C	
										46 •	24	5.19					725	7	C	
										62 •	32	6.99					755	1	C, B	
										35 •	18	3.95					755	4	C, B	
										35 •	18	3.95					755	7	C, B	
										1.30 •	67	14.66					448	1	CO	
										62 •	32	6.99					448	4	CO	
										92 •	48	10.37					448	7	CO	
										74 •	38	8.34					768	1	C	
										26 •	13	2.93					768	4	C	
										46 •	24	5.19					768	7	C	
										64 •	33	8.34					815	1	C	
										25 •	13	2.93					815	4	C	
										89 •	46	10.03					400	1	CO	
										46 •	24	5.19					400	4	CO	
										57 •	30	6.43					400	7	CO	
										84 •	44	0.47					870	1	C	
										33 •	17	3.72					870	4	C	
										33 •	17	3.72					870	7	C	
										85 •	44	9.51					872	4	C	
										33 •	17	3.72					872	7	C	
										1.14 •	59	12.85					280	1	CO	
										26 •	13	2.93					280	7	CO	
										25 •	13	2.87					280	1	CO	
										54 •	28	6.03					555	4	C	
										24 •	12	6.03					555	7	C	
										23 •	12	2.53					555	1	C	
										1.58 •	82	2.91					470	4	CO	

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST BY	TEST YEAR	FURNACE EMISSIONS lb/Mlb	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/Mlb	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	$\% CO_2$	$\% CO$	O_2	H_2O	Temp. °F	REMARKS	
																		Probe	Cycle
19	150		Cylindrical (Batch)		5	1964				.59 *	.31	6.65					470	4	CO
										.34 *	.18	3.83					615	1	C
										.25 *	.13	2.82					615	4	C
										.35 *	.18	3.95					615	7	C
20	250	1962	Cylindrical (Batch)	Wetted baffles	6		.571	.302	6.44 *	.227	.146	3.13*							
							.735	.388	8.29 *	.308	.163	3.48*							
							.848	.448	9.57 *	.262	.138	2.96*							
47		1958	Cylindrical (Batch)	Expansion chamber & wetted baffle plates						.47 *	.243	5.29							
46	240	1964	Cylindrical (Batch)	Water spray on refractory baffls & sewer-type expansion chamber						.24 *	.124	2.70							
										.264*	.137	2.97							
34	150	1954	Cylindrical (Batch)	Expansion chamber & wet baffles (3 rows sprays)			1.153	.609	13.00 *										
32		1956	Cylindrical (Batch)	Expansion chamber & wet refractory baffles						.60 *	.331	6.764						Furnace operating at 65% of capacit	
99			Cylindrical (Batch)		4	1956							4.64	0	14.55	Dry Basis		Sprays off	
													4.60	0	14.82				
													5.88	.2	13.51				
													4.78	.1	14.42				
55	150		Cylindrical (Batch)	Water sprays									2.85	0.2	17.65			Before sprays	
													2.65	0.2	16.65				
													6.35	0.2	13.8				
													5.85	0.2	14.25				
													8.25	0.1	11.8				
													6.65	0.1	13.4				
													7.90	0.1	12.5				
													7.35	0	12.75				
													11.15	0	9.0				
52	150	1952	Cylindrical (Batch)	Sprays, Cyclones	4	1962							6.90	0.80	12.33			Stack gas	
													7.97	0.40	11.62				
													7.55	1.21	11.81				
													4.58	0.10	15.[illegible]				
													4.43	0.10	15.[illegible]				
													5.2	0.10	14.5				
													4.8	0	15.2				

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	REMARKS
					BY	YEAR	lb/MBtu	gr/scf	lb/ton	lb/MBtu	gr/scf	lb/ton	%CO$_2$	%CO	%O$_2$	%H$_2$O	°F	
6	50	1961	Rectangular Rocking (Batch)	Expansion chamber & checkerwood & chain wall and sprays, retractable baffles	4	1961				6.140*	3.186	69.222	2.79	.09	16.97	3.80	498	Furnace operating at 120% of capacity, sprays off, APC inoperative, wet bottom
										7.870*	4.084	88.726	2.29	.58	17.59	3.97	521	
										8.940*	4.639	100.789	2.13	.29	17.23	4.14	574	
										0.853*	.442	9.616	2.67	.09	16.50	6.04	231	1 spray on Furnace operating at 100% of capacity
										0.834*	.432	9.402	2.39	.09	16.92	5.95	254	2 sprays on
										0.832*	.431	9.379	2.55	.19	16.80	5.56	232	2 sprays on
49	90	1956	Rectangular Rocking (Batch)	Multi stage wet baffles		1956	0.48 *	.249	5.411	0.42 *	.217	4.735						
							1.45 *	.752	16.347	0.44 *	.228	4.960						
							2.32 *	1.204	26.155	0.51 *	.264	5.749						
							0.70 *	.363	7.891	0.57 *	.295	6.426						
2	100	1961	Rectangular Rocking (Batch)	Baffled expansion chamber & 3 banks of sprays & multiple cyclone	4	1961	2.89 *	1.500	32.582				4.35	.17	12.83	13.30		Furnace operating at 115% of rated capacity; data noted as furnace emissions are ahead of APC.
							3.009*	1.562	33.923				4.59	.18	13.54	8.59		
							2.720*	1.412	30.665				4.74	.18	12.63	11.10		
										1.080*	.560	12.175	4.71	.18	12.59	11.49		
										1.008*	.523	11.364	4.31	.08	11.88	16.45		
										0.387*	.200	4.363	4.51	.09	12.41	12.65		
							2.850*	1.479	32.131				3.98	.17	13.30	13.87		Furnace operating at 93.3% of rated capacity; data noted as furnace emissions are ahead of APC.
							2.555*	1.326	28.805				3.96	.17	13.24	14.18		
							3.490*	1.811	39.346				3.85	.17	12.95	16.95		
										2.085*	1.821	12.232	3.97	.17	13.35	14.42		
										1.642*	.852	9.606	2.73	.08	14.00	16.80		
										2.390*	1.240	26.944	2.87	.09	14.68	12.57		
71	125	1957	Rectangular Rocking (Batch)	Sprays	4	1960				.21 *	.108	2.367	7.36	.59	5.98	25.32	544	Start up; OF air off
										.22 *	.114	2.480	5.40	.55	8.05	26.90	587	
										.295*	.153	3.325	5.08	.22	10.18	21.70	587	OF air on
										.128*	.066	1.443	5.74	.18	6.40	38.50	578	OF air off
										.257*	.133	2.897	4.95	.12	6.94	38.70	613	
										.162*	.840	1.826	5.73	.20	7.41	31.5	544	OF air on
44	125		Rectangular Rocking (Batch)	Short baffled expansion chamber						1.34 *	.695	15.107					500	
38	100	1963	Rectangular Rocking (Batch)	Wet refractory baffles						.419*	.217	4.723						
22	150	1968	Rectangular Rocking (Batch)	Expansion chamber & 4-stage wet metal baffles (.22-.46" pressure drop) & brick checkerwork 2 1/2" square holes	4	1968				.541*	.280	6.099	3.46	.15	12.23	23.6	530	APC Pressure Drop .42 ("W.C.)
										.291*	.151	3.280	5.09	.09	13.82	7.87	563	Start up .34 ("W.C.)
										.187*	.097	2.108	4.69	.17	12.74	15.10	608	.72 ("W.C.)
										.175*	.090	1.972	4.88	.09	12.95	13.70	612	.46 ("W.C.)

INCINERATOR EMISSION DATA

PLANT NO	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	CO_2	CO	O_2	[illegible]		
22	150	1968	Rectangular Rocking (Batch)	See above	4	1968				215*	111	2 423	4 44	26	13 40	11 92	535	Wet refuse 46
										272*	141	3 063	4 48	08	13 00	15 00	611	required much 45
										198	102	2 232	4 48	09	13 02	14 93	602	manual stoking 46
45	150		Rectangular Rocking (Batch)	Water sprays	7	1951				42 *	271	4 735						Spray off, 300% excess air,
					1	1951				34 *	176	3 833						13,800 lb/hr UF air,
																		262 sq. ft. grate area
10	150	1954	Rectangular Rocking (Batch)	Wetted metal baffles, 8" spacing, 0 6" pressure drop	4	1965	2 4 *	1 245	27 057									minimum in test series
							3 55 *	1 842	20 766									maximum in test series
										94 *	487	10 597						minimum in test series
										1 40 *	726	15 783						maximum in test series
										1 403*	728	15 817	3 58	17	13 68	16 65	641	
										764*	396	8 613	4 58	16	12 18	19 42	706	
										951*	493	10 721	3 56	16	13 58	17 55	716	
										779*	404	8 782	3 87	24	12 74	19 40	730	
										965*	500	10 879	3 77	25	13 14	18 10	728	
										679*	352	7 655	3 70	16	12 94	19 55	738	
										1 211*	628	13 652	3 53	24	13 37	18 45	714	
										761*	394	8 573	3 87	24	12 69	19 73	737	
										1 032*	535	11 634	3 21	16	13 38	11 85	751	
										1 025*	531	11 553	3 72	24	12 92	19 15	670	
										784*	406	8 833	3 67	16	13 22	18 25	642	
										708*	367	9 981	3 66	16	12 79	20 50	674	
										775*	402	8 737	3 96	24	12 38	20 65	679	
										1 045*	542	11 781	3 29	08	13 41	19 65	672	
										751*	389	8 463	3 58	16	12 87	20 65	702	
43	325	1955	Rectangular Rocking (Batch)	Wet bottom secondary and expansion chamber & stainless steel plate						30 *	155	3 382					500	
26	250	1965	Rectangular Rocking (Batch)	Sprays	4					24 *	124	2 705						
										265*	137	2 987						
										31 *	160	3 494						
11		1956	Rectangular Rocking (Batch)	Expansion chamber & baffles	8	1955				36 *	186	4 058						
										60 *	311	6 764						
45				Pilot baghouse silicon treated glass			886	460*	9 801	001	0007*	014	6 0		14 8	0	370	SO_2 in 22 8 ppm, out 26 5
							788	409*	8 714				9 2		16 8	0	600	ppm
							585	304*	6 477				2 6		18 4	0	325	SO_3 in 22 0 ppm, out 0 4
							886	460*	9 801	026	014 *	298						ppm

INCINERATOR EMISSION DATA

PLANT NO	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST BY	TEST YEAR	FURNACE EMISSIONS lb/Mlb	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/Mlb	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	CO_2	CO	O_2	H_2O	Temp °F	REMARKS
67	50		Rectangular Reciprocating (Batch)	Water spray scrubbers (2 baffles)			78 *	40	8 79	57 *	30	6 43						% excess air 235
							1 04 *	54	11 72	55 *	29	6 20						110
							1 79 *	93	20 18	61 *	32	6 88						100
49	90	1956	Rectangular Reciprocating (Batch)	Multi stage wet baffles		1956							7 8	0	10 8	Dry Basis		Scrubber inlet
													4 8	0	14 0			
													3 7	0	16 5			
													4 6	0	14 2			
100			Rectangular Reciprocating (Batch)										1 88	0	18 39			Sprays off
													1 78	0	18 40			
													2 09	0	18 00			
													2 72	0	17 30			
													1 58	0	18 42			
													2 0	0	18 00			
													2 84	0	17 30			
													4 29	0	16 00			
102	50	1960	Rectangular Reciprocating (Batch)	Scrubber									5 7	0 05				Before sprays
													8 8	0 02				
													9 8	0 02				
103	100		Rectangular Rocking (Batch)	None														

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	%CO$_2$	%CO	O$_2$	H$_2$O	°F	REMARKS
40	72	1968	Impact	Cyclonic wet scrubber	9	1968				.334* .340* .340*	.173 .176 .176	3.755 3.833 3.833						

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	%CO$_2$	%CO	O$_2$	H$_2$O	°F	
3	100	1962	1 Traveling Grate (Continuous)	Wet baffles	4	1962	1.31 *	0.680	14.769	.747*	38.769	8.421						
37	120	1963	1 Traveling Grate (Continuous)	Wet bottom expansion & 1 refractory spray baffle						.542*	.281	6.110	3.54	.25	14.28	15.15	416	
										.499*	.258	5.625	3.67	.24	13.24	19.90	444	
										.723*	.375	8.151	3.99	.15	12.62	22.70	519	
										.638*	.331	7.192	3.87	.16	12.50	20.00	509	
										.550*	.285	6.200	3.35	.16	13.13	21.00	463	
										.541*	.280	6.099	3.46	.15	12.23	23.60	530	
35	150	1962	1 Traveling Grate (Continuous)	Circular spray chamber & 12" to 30" diameter cyclones, 3" pressure drop	4					.681*	.353	7.677	5.56	.17	11.48	14.40	529	
										.754*	.391	8.500	4.58	.16	11.30	21.10	555	
										.793*	.411	8.940	4.46	.16	11.13	26.64	572	
										1.038*	.538	11.702	2.50	.17	13.72	13.78	505	
										.922*	.478	10.394	2.76	.16	13.20	19.03	482	
										.847*	.439	9.549	3.23	.17	13.70	14.98	535	
							1.507*	0.782	16.990				4.26	.17	12.30	16.37	447	
							1.192*	0.619	13.437	.591*	.306	6.662	4.17	.16	12.00	18.18	530	
													4.98	.15	10.50	23.40	481	
										.565*	.293	6.369	4.98	.15	10.50	23.45	520	
										.616*	.319	6.944	4.25	.18	13.59	11.30	525	
										.454*	.235	5.118	4.41	.08	11.90	18.05	542	
										.514*	.266	5.794	4.16	.08	12.60	16.63	545	
							1.330*	0.690	14.994				3.81	.09	13.80	11.68	531	
										.821*	.426	9.255	3.73	.09	12.40	14.70	579	
										.600*	.311	6.764	4.31	.08	11.72	19.25	562	
							1.400*	0.727	15.784	.64 *	3.321	7.215						
36	180	1962	1 Traveling Grate (Continuous)	Wet bottom expansion & 1 refractory spray baffle						.889*	.461	10.022	1.81	.39	13.52	21.20	349	
										.801*	.415	9.030	1.98	.16	14.38	17.45	365	
										.785*	.407	8.850	1.76	.23	13.63	23.30	370	
										.940*	.487	10.597	1.77	.15	13.20	22.90	310	
										.786*	.407	8.861	2.38	.15	13.42	23.40	360	
										.984*	.510	11.093	1.77	.25	14.90	17.20	298	
104	100	1955	1 Traveling Grate (Continuous)	Sprays, tray-type scrubber	25					.086	.045*	.958						
										.084	.044*	.937						Dust loading at stack
										.088	.046*	.980						
										.086	.045*	.958						
										.080	.042*	.894						

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 Hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST BY	TEST YEAR	FURNACE EMISSIONS lb/MB	FURNACE EMISSIONS gr/scf	FURNACE EMISSIONS lb/ton	STACK EMISSIONS lb/MB	STACK EMISSIONS gr/scf	STACK EMISSIONS lb/ton	CO2	CO	O2	H2O	Temp °F	REMARKS
56	200	1964	2 Traveling Grates (Continuous)	Cyclone 3.06" pressure drop	10	1965	166*	0.086	1.871	024*	012	270					600	
							145*	0.075	1.635									
75	220		2 Traveling Grates (Continuous)	Expansion chamber & sprays & cyclones	11	1962				094*	050	1.07				14.3	522	After sprays only
										097*	051	1.10				15.0	491	After sprays only
										103*	054	1.17				17.0	500	After sprays only
										101*	053	1.14				15.0	493	After sprays only
77	220		2 Traveling Grates (Continuous)	Pilot tests on electrostatic precipitator	11		1.10 *	0.571	12.401	066*	034	744						Feed 44% private,
							1.17 *	0.607	13.191	066*	034	744						66% municipal collection
							1.14 *	0.592	12.852	118*	061	1.33						Values @ inlet to pilot APC after dilution & spray cooling ppm SO_x as SO_2 ppm SO_x as SO_2
20	250		2 Traveling Grates (Continuous)	Furnace # 1 3 rows of wet baffles Furnace # 2 2 rows & 1 row of wet baffles & 2 large baffles & wetted walls	4	1966				473*	245	5.332	3.64	09	13.84	15.72	392	Furn. # 2 9.2 15.6
										455*	236	5.129	3.70	09	13.20	16.50	402	only 25.7 11.3
										347*	189	3.912	3.48	08	13.40	16.25	373	7.6 9.7
										385*	199	4.430	3.75	08	12.58	16.25	406	Furn. # 1 28.6 125
										400*	207	4.509	3.64	08	13.22	15.85	389	only 62.8 104
										327*	169	3.686	3.70	08	12.68	18.45	401	19.7 112
										294*	152	3.314	4.91	08	10.98	21.60	494	Both
										256*	132	2.886	4.71	08	11.32	20.80	479	Furnaces
										340*	176	3.883	3.78	08	12.08	21.20	471	
													9.0	3	10.0	0		
													8.0	3	11.0	0		
													8.5	2	10.9	0		
													10.3	4	8.7	0		
													7.8	2	11.2	0		
													9.4	3	9.5	0		
													10.0	4	9.2	0		
													11.4	5	7.8	0		
													8.6	2	10.8	0		
													9.4	2	9.6	0		
													8.0	2	11.3	0		
													8.8	2	10.5	0		
													9.85	21	9.01	0		Average of additional data set
					4	1963				447*	231	5.039						

INCINERATOR EMISSION DATA

PLANT NO	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS								REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	% CO_2	% CO	% O_2	% H_2O	Temp °F	
14	250		2 Traveling Grates (Continuous)	Wet bottom expansion chamber	12	1964				1.68*	.871	18.940	2.6	0	17.2	0	782	Calculated efficiency of collection 32%
										1.68*	.871	18.940	3.2	0	17.2	0	863	
										1.98*	1.027	22.322	3.2	0	17.2	0	938	
										2.03*	1.053	22.886	4.0	0	16.4	0	881	
										1.62*	.840	18.263	4.0	0	16.8	0	822	
										1.70*	.882	19.165	4.0	0	16.8	0	861	
										2.13*	1.105	24.013	2.2	0	18.2	0	738	
										2.43*	1.261	27.395	2.2	0	18.2	0	723	
30	250	1965	2 Traveling Grates (Continuous)	Impingement sprays						.394*	.204	4.441	3.5			27	500	Furnace 1950°F Breeching 630°F
33	300	1960	2 Traveling Grates (Continuous)	Water cooled chamber & cyclone (refractory lined)						.90*	.467	10.146						
76	250	1954	2 Traveling Grates (Continuous)	Dry expansion chamber	13	1962				1.44	Relative Values							Furnace Temp / ppm* Org. Acids / % UF Air / UF Air Mcfm 1750°F 1074 20 11.9 1790°F 1097 50 12.2 1930°F 1152 80 12.5 1960°F 1469 100 12.2 * @ 50% excess air Poor burning @ 20% UF air required "excessive hand stoking NO_x, Ald. lowest @ 90% UF HC, Benzpyrene no change during tests
										1.00								
										1.17								
										1.59								
68	250		2 Traveling Grates (Continuous)	Expansion chamber			3.8 *	20	42.84									% excess air 190
							2.8 *	15	31.57									180
							3.3 *	17	37.20									190
							4.6 *	24	51.86									150
78	250	1956	2 Traveling Grates (Continuous)				.887	.469	10.0 *									Test series on effect of UF air Increase in dust load with increase in underfire air noted 150 300% excess air
							1.064	.562	12.0 *									
							1.153	.609	13.0 *									
							1.507	.797	17.0 *									
							1.596	.844	18.0 *									
							2.128	1.125	24.0 *									
							2.217	1.172	25.0 *									

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS								
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	%CO_2	%CO	O_2	H_2O	Temp °F	REMARKS
73	240	1963	2 Traveling Grates (Continuous)	Wet refractory baffles						.893*	.463	10.067						
17	250	1959	2 Traveling Grates (Continuous)	Baffle (Skimmer & horiz) in wet expansion chamber	12	1963	.896*	0.465	10.102	.767*	.398	8.647						
18			2 Traveling Grates (Continuous)	Baffle (Skimmer & horiz) in wet expansion chamber	12	1963	1.12 *	0.581	12.627	.83 *	.430	9.357						
25	300	1963	2 Traveling Grates (Continuous)	Spray & baffle	15					.767*	.398	8.647						
57	220	1957	2 Traveling Grates (Continuous)	Pilot electrostatic precipitator			1.14 *	0.592	12.852	.083*	.043	.935						
													10.4	0	9.2			
													7.0	0	13.2			
													13.0	0	6.4			
													12.4	0.1	6.4			
													9.2	0.2	7.6			
													10.6	0	9.2			Furnace outlet
						1962							13.8	0	5.2			
													16.2	0	2.8			
													9.4	0	9.4			
													10.5	0	8.6			
													11.0	0	8.0			
95	250	1953	2 Traveling Grates (Continuous)	Dry expansion chamber		1953							11.2	1.8	6.7			
													7.4	1.8	10.5	Dry Basis		
													15.0	0	2.6			Furnace outlet
													6.6	0	13.1			
													10.6	0	9.1			
96	250	1959	2 Traveling Grates (Continuous)	Dry expansion chamber		1959							8.4	0	11.4			
													9.5	0	10.3			
													9.6	0	10.0			
													6.2	0	13.6			
													8.0	0	11.9			
							1953						1.6	0	18.2			Furnace outlet
													1.0	0	19.0			
													1.6	0	18.0			
													2.6	0	17.0			
													2.5	0	16.7			

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS			%CO$_2$	%CO	%O$_2$	%H$_2$O	Temp °F	REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton						
96	250		2 Traveling Grates (Continuous)	Dry expansion chamber		1953							1.6	0	17.6	Dry Basis		Furnace outlet
													4.4	0	16.0			
													2.19	0	17.5			
													7.1	.0020	12.6			
													6.3	.0028	13.6			
													6.0	.0036	13.9			
													6.4	.0026	13.7			
76	250	1954	2 Traveling Grates (Continuous)	Dry expansion chamber									7.8	0	12.6			Furnace outlet
													11.9	0	7.8			
													10.7	0	9.0			
													9.0	0	11.0			
													11.2	0	8.6			
													10.12	0	9.8			
													3.4	.4	17.1			
													6.1	0	12.8			
													4.3	0	15.3			
													3.6	0	16.8			
													4.6	0	15.1			
													3.7	.08	15.42			
													4.7	.10	15.11			
													4.9	.10	15.03			
													5.3	.10	14.31			
													5.1	.10	14.63			
													5.1	.10	14.60			
													6.4	.10	13.51			
													6.4	.20	13.52			
													4.7	.15	15.22			
													4.2	.10	16.0			
													5.5	.10	14.24			
													5.5	.10	14.22			
													6.8	.20	13.42			
													6.8	.20	13.43			

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	REMARKS
					BY	YEAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	CO_2	CO	O_2	H_2O		
1	250	1966	3 Traveling Grates (Continuous)	Spray baffle - water recirculated	4	1968				0 936*	457	10 562	2 61	18	16 28	9 02	429	Start up
										0 731*	379	8 241	3 00	18	15 38	12 12	434	
										0 731*	379	8 241	2 72	18	15 82	11 66	485	
										1 171*	607	13 201	3 23	17	15 42	15 25	515	Cleaning going on
										0 975*	506	10 992	2 60	17	15 00	15 75	540	
										0 771*	400	8 692	2 60	25	14 97	15 83	543	
													3 2	1	17 0	Orsat Gas Analyses - Dry Basis		
													2 8	2	17 6			
													2 7	2	18 1			
													2 5	3	18 4			
													2 5	3	18 4			
													2 5	2	18 3			
													3 4	3	17 5			
													3 5	2	17 3			
													3 0	2	17 8			
													3 0	2	17 9			
													2 5	2	18 5			
													2 2	3	18 7			
													3 0	2	17 8			
													3 4	2	17 5			
													2 5	2	18 3			
													2 4	2	18 5			
													2 8	3	18 2			
													1 4	3	19 4			
													2 3	1	18 7			
													2 9	2	18 0			
													2 1	3	18 8			
													4 2	1	16 6			
													3 5	3	17 5			
													3 5	3	17 3			
													2 5	3	18 2			
													3 9	2	17 4			
													3 4	3	17 3			

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 H	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS	
					BY	YEAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			% excess air
28	120	1965	Rocking Grate (Continuous)	Wet bottom expansion chamber & one spray-wet refractory baffle	4					600*	311	6.764	4.93	08	10.35	20.6	560	Sprays at 25 psi incomplete baffle wetting suspected	
										624*	323	7.034	4.57	16	10.90	22.3	570		
										630*	224	7.102	4.67	08	11.18	22.4	548		
										432*	224	4.870	4.95	24	11.22	21.1	455	Sprays at 30 psi	
										500*	259	5.637	4.70	08	10.95	21.9	451		
										468*	242	5.276	4.56	08	10.74	23.4	431		
48	125	1963	Rocking Grate (Continuous)	Baffles, wet bottom expansion chamber & 2 spray banks	4		1.070*	0.555	12.063	79 *	410	8.906						Furnace operating at 122% of rated capacity	
										1.070*	555	12.063	4.85			0		Furnace operating at rated capacity	
										1.680*	352	7.666	5.60			0			
										0.753*	390	8.489	5.08			0			
										0.880*	456	9.921	5.34			0			
										0.721*	376	8.128	6.10			0			
										0.954*	495	10.755	5.77			0			
7	150	1966	Rocking Grate (Continuous)	Wet close-spaced baffles	16	1968				1.46 *	757	16.460	4.2					2 furnaces 14,300 cfm UF air, about 1,000 cfm OF air, 9' × 34' grate	
										3.66 *	1.899	41.262	3.5						
										1.58 *	[illegible]	17.812	3.3						
										1.70 *	882	19.165	3.1						
										1.44 *	747	16.234	4.3					1 furnace	
										1.71 *	887	10.278	3.2						
21	250	1966	Rocking Grate (Continuous)	Wet scrubber impingement trays	17	1966				53 *	275	5.975	7.3	0	12.7	0		4 stokers/furnace, one 2' drop a long grate	150
										33 *	171	3.720	5.8	0	14.2	0			204
										32 *	166	3.607	7.0	0	13.0	0			159
										23 *	119	2.593	5.4	0	14.8	0			231
										24 *	124	2.705	10.0	0	9.8	0			86
										35 *	181	3.945	5.0	0	15.0	0			243
13	250	1965	Rocking Grate (Continuous)	Wet expansion chamber & sprays on wet baffle	18	1960				3 *	155	3.382						Average of test series	
27		1957	Rocking Grate (Continuous)	Water sprays	4					1.190*	617	13.416	4.48	19	14.8	4.44	451	Sprays off	
										784*	406	8.938	5.35	19	14.2	5.40	467	Sprays off	
										1.060*	550	11.950	5.11	19	14.04	6.49	480	Sprays on (42 psi)	
										1.025*	531	11.555	4.97	18	13.75	8.34	472	Sprays on (42 psi)	
										1.076	550	12.130	5.07	19	14.00	7.39	480	Sprays on (42 psi)	
60			Rocking Grate (Continuous)	Sprays @ 30-35 psi	4	1966				250*	129	2.818	4.37	07	10.5	26.7	336		
										335*	173	3.776	4.15	14	10.77	28.3	304		
										330*	171	3.720	4.79	07	9.67	31.0	331		

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp	
					BY	YEAR	lb/MBtu	gr/ft³	lb/ton	lb/MBtu	gr/ft³	lb/ton	CO_2	[illegible]	O_2	[illegible]	°F	REMARKS
16	200	1958	Rocking Grate (Continuous)	Wet expansion chamber & wet baffles	4	1959				14 * 286* 2 86 * 2 16 *	072 148 1 484 1 121	1 578 3 224 32 243 24 351						

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS								REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	% CO_2	% CO	% O_2	% H_2O	Temp °F	
51	87.5	1963	Reciprocating Grate (Continuous)	Sprays, wet baffles			2.69*	1.396	30.327	71*	368	8.004						
12	150	1963	Reciprocating Grate (Continuous)	Expansion chamber & coarse baffled spray chamber	20		2.4 *	1.245	27.057									Minimum in test series
							3.55*	1.842	40.022									Maximum in test series
										94*	487	10.597						Minimum in test series
										1.4 *	.726	15.783						Maximum in test series
91	200	1968	Reciprocating Grate (Continuous)	Wet baffle wall & multiple cyclone	16	1969				4.42*	2.293	49.831	3.46			Dry Basis		Furnace operating at 118 of capacity, refuse 3872 l lb. 41.4% volatile, 30.4% ash and 28.2% moisture
										3.95*	2.050	44.532	3.72					
										2.77*	1.437	31.228	3.21					
										3.52*	1.826	39.684	2.62					
										1.63*	.845	18.376	2.72					
										2.10*	1.089	23.675	3.15					
										2.16*	1.121	24.351	3.37					
										2.58*	1.339	29.086	3.32					
										1.49*	.773	16.798	3.47					
93	250	1963	Reciprocating Grate (Continuous)	2 banks of sprays with partial baffle wall	16	1968				1.13*	.586	12.739	4.5	0	14.6	0		Refuse 58.7% paper 12.2% food 8.6% metals 10.3% glass 18.8% moist 74% volatile 26% ash
										1.07*	.555	12.063	5.0	0	15.0	0		
										1.31*	679	14.768	5.1	0	14.2	0		
										1.26*	653	14.205	5.2	0	14.4	0		
92	300	1963	Reciprocating Grate (Continuous)	2 banks of sprays with partial baffle wall	16	1968				1.20*	.622	13.520	4.6	0	15.0	0		Refuse 53.2% paper 17.5% food 8.8% metals 6.5% glass 21% moistur 77.3% volati 22.7% ash 5530 Btu/hr
										0.86*	.446	9.695	3.4	0	16.0	0		
										1.60*	830	18.038	3.0	0	17.1	0		
										1.46*	757	16.460	3.4	0	16.5	0		
42	150	1963	Reciprocating Grate (Continuous)	Expansion chamber & sprays & tray scrubber & mist eliminators						35*	181	3.945						Emission data based on calculated gas compositio

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS
					BY	YEAR	lb/MB	gr/scf	lb/ton	lb/MB	gr/scf	lb/ton	CO_2	CO	O_2	H_2O		
15	300	1963	Grate & Kiln	Wet expansion chamber & spray (boiler)	4	1963				74 *	384	8 342						Average of test series
										12 *	062	1 352						
										31 *	160	3 494						
39	300		Grate & Kiln	Spray chamber & baffle (2 sets in series)	19	1963				23 *	119	2 593						Average of test series #1
										342*	177	3 855						Maximum in test series #1
										56 *	290	6 313						Average of test series #2
										45 *	233	5 073						(correct value uncertain)
										806*	418	9 086						Maximum in test series #2
15	300	1963	Grate & Kiln	Wet expansion chamber, 2 spray chambers	4	1963				797*	413	8 985	4 49	15	11 10	22 82	501	Manual sprays on 4 turns
										613*	318	6 910	4 21	17	12 3	15 78	714	Manual sprays
										860*	446	9 695	3 33	25	13 1	16 75	736	on 2 turns, 800°F
										609*	316	6 863	3 69	17	13 48	14 20	780	automatic

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS
					BY	YEAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	CO_2	CO	O_2	H_2O		
63	50		Unknown				0.718	0.373	8.1*									% excess air 110 Measured in breeching to scrubber
58	65		Unknown		16		1.375 0.461	0.714 0.239	15.5* 5.2*									% excess air 220 UF air 220 OF air High arch, mechanically stoked
61	70		Unknown				0.435 0.213 0.142	0.226 0.110 0.074	4.9* 2.4* 1.6*									% excess air 480 UF air 380 OF air 480 OF air (start up) Low arch, mechanically stoked
82	110		Unknown	None						754* 683*	40 36	8.50 7.70	2.7 4.1			32.5 31.8	383 389	
81	100		Unknown	Unknown						722*	382	8.15	3.2			27.5		
31	125	1954	Unknown	Large flues 15' × 48' × 100' long with baffles						515*	267	5.806						It is said 14.5 lb ash/ton are collected from flues
95	125	1961	Unknown	Large flues 15' × 48' × 100' long with baffles						515*	267	5.806						
53	150	1951	Unknown	No APC but large flues give expansion chamber effect						78* 625*	404 324	8.793 7.042	6.55 6.67		12.50 12.3	0 0	1175 1210	UF air and sprays off
41	150	1957	Unknown	Water sprays						820* 874*	425 453	9.244 9.853						

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	%CO₂	%CO	O₂	H₂O		
80			Unknown				1.153	.609	13.0*									150-300% excess air
							1.241	.656	14.0*									
							.975	.515	11.0*									
							.975	.515	11.0*									
							.975	.515	11.0*									
							1.153	.609	13.0*									
							1.241	.656	14.0*									
							1.241	.656	14.0*									
79	250		Unknown				1.951	1.031	22.0*									150-300% excess air Increase in dust load with increase in underfire air noted High yard waste refuse
							2.040	1.078	23.0*									
							3.281	1.733	37.0*									
							4.080	2.157	46.0*									
70	200	1966	Unknown	Wet bottom expansion chamber (7200 cu. ft.) & 4 banks of sprays & 24, 30" diameter cyclones						.224*	.116	2.525						Furnaces 1, 2, & 3
										.234*	.121	2.638						Furnaces 1, 2, & 3
										.270*	.140	3.043						Furnaces 1 & 2
										.237*	.123	2.671						Furnaces 1 & 2
										.266*	.138	2.998						Furnaces 1 & 2
										.322*	.167	3.630						Furnaces 1 & 2
										.271*	.140	3.055						Furnaces 1, 2, & 3
										.260*	.134	2.931						Furnaces 1, 2, & 3
										.209*	.108	2.356						Furnaces 1 & 3
										.200*	.103	2.254						Furnaces 1 & 3
																		1. Stack temperature 457-487°F during tests. 2. Stack gas composition range (dry basis) CO₂ 3.2-4.2% O₂ 15.2-16% CO 0.0-0.3% 3. Measured efficiency (based on unit inlet load) Unit Expansion 31.1% Spray 69.4% Cyclone 62.3% Ducts to Stack 21.0%
72			Unknown	Probably wet expansion chamber						858*	.445	9.673						Average flue gas moisture 20%. 20% excess air
										924*	.479	10.417						
										865*	.448	9.752						
										1.378*	.715	10.417						
										1.100*	.570	9.752						

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS								REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	%CO₂	%CO	O₂	H₂O	Temp °F	
23			Unknown	"Scrubbers"						346*	179	3.900						Average moisture 43.6%.
										405*	.210	4.565						84% excess air.
										305*	.158	3.438						This run with maximum wate
																		pressure
50			Unknown	Turbulent contact absorber, scrubber & precool spray	21	1969	3.89*	2.019	43.856									APC inlet Temp. 700-1150°F
										80 *	.415	9.019						APC outlet temp. 130-170°F
										88 *	.456	9.921						
																		190% excess air
62			Unknown				1.597	0.820	18.0 *									Measured in breeching to stac
97			Unknown										6.4	0	14.0	Dry Basis		At inlet to sprays
													8.0	0	12.0			
98			Unknown										5.86	0	14.24			Flue gas after sprays
													5.81	0	14.40			
													4.50	0	15.18			
													4.65	0	15.32			
													2.05	0	17.37			
101			Unknown	Wet Collector	4	1957							5.0	0.10	14.93			Stack gas
													5.4	0	14.60			
													5.85	0	14.15			
													5.75	0.10	14.20			
													4.62	0	15.33			
													5.51	0	14.40			
													6.01	0	14.03			
102	50	1960	Unknown	Batch scrubber		1961							5.7	0.05	14.7			Before sprays
													8.8	0.02	11.0			
													9.8	0.02	10.4			

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp		REMARKS
					BY	YEAR	lb/Mlb	gr/scf	lb/ton	lb/Mlb	gr/scf	lb/ton	% CO$_2$	CO	O$_2$	H$_2$O	°F	Test	Outlet gr/m^3 *
94 (European)	100	1966 ?	5 Traveling Grates (Continuous)	Air dilution & evaporative cooling & electrostatic precipitator	24	1967											391	1	110
																	381	1	094
																	423	1	117
																	401	1	0947

* 760 mm, 0°C no CO$_2$ correction

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp		REMARKS	
					BY	YEAR	lb/MBtu	gr/SCF	lb/ton	lb/MBtu	gr/SCF	lb/ton	CO_2	CO	O_2	H_2O	°F			
59 (European)	100	1958	Reciprocating Grate (Continuous)	Electrostatic Precipitator, 20,000 pph boiler						.298	0.150	3.196*						2 stage		
										.096	0.050	1.065*						3 stage		
										.067*	0.034	0.775						3 stage		
66 (European)	360	1964	Reciprocating Grate (Continuous)				5.410	2.860	61.0 *								356	Minimum in test series		
							10.555	5.581	111.0 *									Maximum in test series		
																		Reported 99.4% APC efficiency		
90 (European)	360	1965	Reciprocating Grate (Continuous	Electrostatic Precipitator (boiler)		1965	5.428	2.816	60.00	.108	.056	1.200						APC EFFICIENCY	FURNACE #	FLUE GAS DEW POINT
							5.170	2.682	57.15	.065	.033	.720						(1) 98.0		
										.012	.066	.135					428	97.9		130
							3.705	1.921	40.95	.052	.027	.585					432	(1) 98.5		130
							3.867	2.006	42.75	.052	.028	.600					436	97.9		130
							4.275	2.217	47.25	.044	.023	.495					424	98.6		130
							8.733	4.540	96.75	.028	.014	.315					432	(1) 98.3		126
							4.736	2.456	52.35	.051	.026	.370					423	98.7		126
							6.039	3.132	66.75	.036	.019	.405					427	(1) 96.9		130
							3.203	1.661	35.40								421	(1) 98.3		130
							4.573	2.372	50.55	.044	.023	.459								
							3.732	1.936	41.25	.032	.016	.360					427	98.5		130
							1.343	.696	14.85	.022	.011	.249					432	98.5		133
							2.768	1.436	30.60									98.32	1	
							5.347	2.775	59.10										2	
							6.514	3.379	72.00										1	
							4.125	2.140	45.60	.026	.013	.294							2	
							3.135	1.626	34.65	.042	.022	.474						99.25	1	
							8.712	4.519	92.30									98.63	2	
							2.578	1.337	28.50										1	
										.037	.019	.420							2	
							4.892	2.537	54.075	.252	.130	2.790							1	
							1.284	.665	14.190	.173	.090	1.920						94.85	2 high	
							2.105	1.481	23.265	.242	.126	2.685						96.56	1 rubber	
										.166	.086	1.845						88.57	2 refuse	
							4.171	2.164	46.125	.034	.017	.378							1	
							2.277	1.693	25.170									99.25	1	
							4.885	3.439	54.00	.027	.014	.300							2	
							3.430	1.779	37.920	.031	.016	.343						99.45	1	
							2.761	1.432	30.525	.025	.013	.279						99.00	2	
							3.923	2.035	43.365	.015	.007	.169						99.07	1	
							4.648	2.411	51.375	.026	.013	.297						99.61	2	
																		99.42	1	
								(See note below)			(See note below)									

Note Original data in units of g/Nm^3

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS								REMARKS
					BY	YEAR	lb/MBtu	gr/scf	lb/ton	lb/MBtu	gr/scf	lb/ton	% CO_2	% CO	O_2	% H_2O	Temp °F	
90 (European)	360	1965	Reciprocating Grate (Continuous)	Electrostatic precipitator (boiler)		1965	2.263	1.174	25.020	020	010	.222						99.1 2
										038	.019	.426						1
							1.695	.879	18.735	.042	.021	.465						97.5 2
							1.799	.933	19.890	.043	.022	.483						97.54 1
							5.428	2.815	60.00	.088	.045	.975						98.38 2
							6.554	3.400	72.45	.029	.015	.321						99.56 1
							5.496	2.851	60.75	.062	.032	.690						99.87 2
							7.640	3.963	84.45	.042	021	.468						99.45 1
							3.013	1.562	33.30	.018	.009	.210						99.37 1
							3.227	1.674	35.67	025	.013	285						99.2 2
							3.010	1.561	33.27	.025	.013	.279						99.2 1
							2.901	1.505	32.070	.029	.015	.324						99.0 2
							2.934	1.522	32.430	.014	.007	.156						99.6 1
							5.102	2.65	56.40	.054	.019	.405						99.28 2
							3.236	1.679	35.775	014	.007	.157						99.56 2
							1.846	.957	20.40	019	.010	.220						98.92 1
							2.557	1.323	28.20	.011	.006	.128						99.34 2
							2.760	1.431	30.510	047	.024	.525						98.27 1
							(see note below)			(see note below)								Notes (1) = with shot blastin and soot blowing
																		Refuse 40-45% moisture 50-55% combust 2-2.5% plastics 3% residue 1800 k cal/kg lower heating val
88 (European)	600	1964	Reciprocating Grate (Continuous)	Electrostatic precipitator (boiler)	22	1965	20.993	10.891	232.05	024	012	.270	8.9		11.9	14.2	320	No soot blowing, refuse v 42% ash
74 (European)			Reciprocating Grate (Continuous)	Sprays		1967				6.493	3.37 *	71.80			17.6		599	Cooling sprays only
										5.195	3.07 *	65.415			18.0		585	Cooling sprays only
										5.838	3.03 *	64.563			18.2		567	Knock out & cooling spra
										4.585	2.38 *	50.713			17.3		608	Knock out & cooling spra
65 (European)			Reciprocating Grate (Continuous)	Waste heat boiler & electrostatic precipitator			1.26*	0.654	14.205	031*	016	.349						

Note Original data in units of g/Nm^3

INCINERATOR EMISSION DATA

PLANT NO.	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS			%CO$_2$	%CO	%O$_2$	%H$_2$O	Temp °F	REMARKS
					BY	YEAR	lb/MBtu	gr/scf	lb/ton	lb/MBtu	gr/scf	lb/ton						
89 (European)	240		Barrel (Continuous)	Electrostatic precipitator (boiler)	22	1967	1.490 1.782	7.730 9.244	164.70 196.95	048 056	025 029	540 630	10.5 10.4		9.3 9.5		480 480	911 kg/hr collected dust 1098 kg/hr collected dust Dew point = 128°F Refuse 30% moisture 25% paper 45% other combustible (net about 30% ash)
							(See note below)			(See note below)								

Note: Original data in units of g/Nm^3

INCINERATOR EMISSION DATA

PLANT NO	FURNACE CAPACITY T/24 hr	START UP DATE	GRATE TYPE	AIR POLLUTION CONTROL	TEST		FURNACE EMISSIONS			STACK EMISSIONS							Temp °F	REMARKS
					BY	YEAR	lb/MBtu	gr/scf	lb/ton	lb/MBtu	gr/scf	lb/ton	CO_2	CO	O_2	H_2O		
87 (European)	267	1966	Unknown	Electrostatic precipitator, spray conditioning tower (1 4" pressure drop)	23	1966	1 069	0 635*	11 826	040	021*	447						15 8 tons/hr firing rate APC efficiency 96 18%
64 (Unknown)			Unknown	Waste heat boiler & electrostatic precipitator			1 15 *	0 597	12 965	062 *	032	698						
24 (Unknown)		1969	Unknown	Electrostatic precipitator			2 47 * 83 *	1 282 0 431	27 847 9 357	126 *	065	1 420						Winter Summer

ABBREVIATIONS USED IN SUMMARY OF INCINERATOR EMISSION DATA

Plant No. – Code number for incinerator location (may include more than one furnace type)

"By" in Test column denotes code number of emission test agency.

* – Original data units

UF – Underfire Air

OF – Overfire Air

Pollutants

Ald – Aldehydes

NO_x – Nitrogen Oxides – Reported as NO_2

SO_x – Sulfur Oxides – Reported as SO_2

HC – Hydrocarbons

Org. Acids – Mixed Organic Acids – Reported as Acetic Acid

Emission Units

lb/Mlb – pounds of particulate emitted per 1,000 pounds of wet flue gas, corrected to 50% excess air

gr/scf – grains of particulate emitted per 1,000 cubic feet of wet flue gas, corrected to 70°F, 50% excess air

lb/ton – pounds of particulate emitted per ton of refuse charged

INDEX RELATING PLANT NUMBER TO SHEET NUMBER, WITHIN TABLE J-1

Plant Number	Sheet Number	Plant Number	Sheet Number	Plant Number	Sheet Number	Plant Number	Sheet Number
1	15	27	16	53	20	79	21
2	6	28	16	54	1	80	21
3	10	29	3	55	3	81	20
4	2	30	12	56	11	82	20
5	2	31	20	57	13	83	2
6	6	32	5	58	20	84	2
7	16	33	12	59	24	85	2
8	3	34	5	60	16	86	2
9	3	35	10	61	20	87	27
10	7	36	10	62	22	88	25
11	7	37	10	63	20	89	26
12	18	38	6	64	27	90	24,25
13	16	39	19	65	25	91	18
14	12	40	9	66	24	92	18
15	19	41	20	67	8	93	18
16	17	42	18	68	12	94	23
17	13	43	7	69	2	95	20
18	13	44	6	70	21	96	13,14
19	3,4,5	45	7	71	6	97	22
20	5,11	46	5	72	21	98	22
21	16	47	5	73	13	99	5
22	6,7	48	16	74	25	100	8
23	22	49	6	75	11	101	22
24	27	50	22	76	12,14	102	8
25	13	51	18	77	11	103	8
26	7	52	3	78	12	104	10

TABLE J-2

NITRIC OXIDE DATA BANK

Test Series	Plant Capacity TPD	Refuse Burned	Emission Lb/Ton	Emission Lb/10^6 Btu
1[a]	3	Cellulosic 25% H_2O $\Delta H_c \cong 6{,}300$ Btu/lb	2.1	0.17
			2.1	0.17
			2.4	0.19
			2.9	0.23
			1.9	0.15
			2.0	0.16
			2.2	0.17
			2.0	0.16
			2.9	0.23
			2.2	0.17
			1.9	0.15
			2.6	0.21
			2.4	0.19
			2.3	0.18
			2.1	0.17
			2.1	0.17
2[b]	250	Municipal $\Delta H_c \cong 4{,}417$ Btu/lb	3.0	0.34
			3.1	0.35
			2.2	0.25
			2.5	0.28
3[b]	50	Municipal $\Delta H_c \cong 4{,}417$ Btu/lb	3.2	0.36
			2.3	0.26
			1.4	0.16
4[c]	3	Cellulosic 50% H_2O $\Delta H_c \cong 4{,}200$ Btu/lb	0.83	0.10
			1.2	0.14
			1.2	0.14
			0.53	0.06
			1.7	0.20
			2.1	0.25
			0.64	0.08
			0.73	0.09
			2.6	0.31
			2.4	0.29
			1.5	0.18
			1.1	0.13
			5.2	0.62
			3.2	0.38
			2.4	0.29
			1.2	0.14

TABLE J-2 (Continued)

Test Series	Plant Capacity TPD	Refuse Burned	Emission Lb/Ton	Emission Lb/10^6 Btu
5^c	3	Cellulosic 25% H_2O $\Delta H_c \cong$ 6,300 Btu/lb	2.1	0.17
			2.3	0.18
			2.5	0.20
			2.2	0.175
			3.0	0.24
			2.5	0.20
			2.6	0.21
			2.8	0.23
			2.6	0.21
			2.9	0.23
			3.2	0.25
			2.3	0.18
			2.8	0.22
			3.2	0.25
			3.6	0.29
6^d	3	Asphalt Saturated Tar Roofing $\Delta H_c \cong$ 13,500 Btu/lb	1.8	0.07
			2.1	0.08
			5.2	0.19
			4.2	0.16
			4.0	0.15
			3.8	0.14
			4.7	0.17
			3.3	0.12
			4.1	0.15
			4.5	0.17
			3.6	0.13
			3.8	0.14
			3.9	0.14
			3.6	0.13
			4.2	0.16
			4.4	0.16
			4.4	0.16
			5.1	0.19
			4.4	0.16
			4.5	0.17
			4.7	0.17
			5.2	0.19
			4.7	0.17
			5.6	0.21
			4.8	0.18
			5.0	0.19
			4.4	0.16
			5.7	0.21
			3.0	0.11
			3.4	0.13

TABLE J-2 (Continued)

Test Series	Plant Capacity TPD	Refuse Burned	Plant Number**	Emission Lbs/Ton	Emission Lbs/10^6 Btu
7	250	Municipal*	20	1.48	0.168
				1.63	0.185
				1.61	0.182
8	100	Municipal*	--	1.8	0.204
9	100	Municipal*	--	2.1	0.237
10	300	Municipal*	--	2.5	0.284
11	90	Municipal*	49	2.46	.278
				1.76	.199
				3.73	.422
				5.05	.572
				4.58	.518
				1.65	.187
				3.65	.413
				5.36	.606
				3.72	.421

STATISTICAL SUMMARY

		No. Points	Arithmetic Average	Standard Deviation
1.	All Data	99	0.2126 lbs/10^6 Btu	0.1044 lbs/10^6 Btu
2.	Series 1,4,5,6 (Small Units)	77	0.1879 lbs/10^6 Btu	0.0866 lbs/10^6 Btu
3.	Series 2,3,7-11 (Large Units)	22	0.3122 lbs/10^6 Btu	0.1325 lbs/10^6 Btu

* Based on standard refuse composition
(Appendix C and Table IV-9): 4450 Btu/lb (HHV)

** Table J-1

REFERENCES

a. *Journal of the Air Pollution Control Association.* Vol. 8 (4), February 1959, pages 297-309

b. *Journal of the Air Pollution Control Association.* Vol. 10 (2), April 1960, pages 114-20

c. *Journal of the Air Pollution Control Association.* Vol. 11, (8) August 1961, pages 376-83

d. *Journal of the Air Pollution Control Association.* Vol. 12 (2), February 1962, pages 83-9

APPENDIX K

CAUSES AND CURES FOR INCINERATOR DEFICIENCIES AFFECTING CRITERIA OF PERFORMANCE

APPENDIX K

CAUSES AND CURES FOR INCINERATOR DEFICIENCIES AFFECTING CRITERIA OF PERFORMANCE

This appendix presents a detailed evaluation of incinerator problems and specific actions for their solution. Interaction of these specific actions with other aspects of incinerator performance are identified by use of a unique "parameter number" concept discussed below. The purpose and method of use for this evaluation are described in Section VII-C of Volume I. It is suggested that the text be reviewed prior to use of the material found here.

Problem solution is aided by a structured approach to identify deficiencies (symptoms), the reasons for the deficiency (causes), and the specific corrective actions recommended (cures). The following pages are organized using such a structure: grouping *symptoms* according to the five performance criteria discussed in Part D of Appendix H, listing the *causes* associated with the symptoms, and suggesting *cures* for those causes.

Following the evaluation method described in Section VII-C, the reader will be able to identify one or more cures which will seem appropriate to solve his current plant problems. There is, however, a possibility that implementation of a given cure will create new problems affecting other aspects of plant performance. To show such interactions, the cures have been reviewed and their effect on various plant parameters evaluated. These parameters are:

Parameter No.	**Parameter**
1	Waste water generation
2	Plant operating costs (excluding debt cost)
3	Underfire air
4	Overfire air
5	Flue gas volume flow rate
6	Flue gas mixing
7	Plant safety
8	Grate damage
9	Refuse composition and properties
10	Pit holding time
11	Refuse firing rate
12	Stoking characteristics
13	Moisture content of flue gases
14	Combustion control
15	Fan capacity
16	Siftings problems

In the paragraphs below, where causes and cures are discussed in detail, each cure which was felt to have a significant effect on one or more of these ① parameters was marked with circled numbers, designating the parameter number. The following example shows the appearance of the text.

Cure 1 – Reduce overfire air velocity ④ ⑥ ⑭

Cure 2 – Moisten refuse ① ⑬ ⑭

For cure 1, as an example, the parameter numbers 4, 6, and 14, suggest that ④ prior to implementing cure 1, the reader should consider other incinerator problems which are also influenced strongly by overfire air, flue gas mixing, and combustion control. These other problems (also marked with the number or numbers 4, 6, or 14), are those which could be significantly improved or worsened by implementing cure 1. This process will usually identify considerations ⑥ which both support and detract from the decision to carry out a given cure. The judgment as to which of the effects is most important must be determined by the reader in the context of his unique needs and plant situation.

To facilitate the process of finding these related problems as they appear throughout the text, the parameter numbers associated with each cure are also typed in the margin of the page on which the Cure discussion first appears. Continuing with the example for cure 1, the reader who has tentatively decided to implement cure 1 should page through the *entire* Causes and Cures section of the report to identify and read of other plant problems which have been similarly marked with parameters 4, 6, or 14. To assist the reader in the mechanics of this process, the final page of the causes and cures text is a fold-out which lists the parameters and parameter numbers; indicates where along the margin the parameter numbers will appear; and provides spaces for notes and references (page K- 57). This appendix has been purposely printed on one side of the page only to afford the reader ample space on which to jot pertinent notes.

There is no question that this a laborious process. If it is done carefully, ⑬ however, the reader hopefully will have before him a comprehensive picture of the impact of a proposed solution to a given problem on the total incineration system. If this appears difficult or complicated, it is, at least partly, a reflection of ⑭ the complexity of an incinerator.

CRITERION I: ENVIRONMENTAL POLLUTION

A. AIR POLLUTION

Symptom A1: Excessive, Noncombustible Particulate Emission

The probable mechanisms of noncombustible, particulate pollutant formation are discussed in some detail in Section V-B of this report, which deals with the nature and causes of incinerator air pollution. It is suggested that the reader review this portion of the report in order to gain understanding of the operation of his own plant and the justification for the causes and cures.

During Charging ⑤

- Cause 1: During batch charging, air currents accompanying the opening of the charging door suspend particulate from the flues.

  Cure 1: Convert batch feed to a continuous or air-lock-type feed system ⑤ ⑭ ⑮

Batch-fed incinerators would benefit from the use of an air-lock-type feed system. In most batch units, a large volume of cold air enters the furnace at the time of charging. The rush of air suspends particulate from the flues. Other disadvantageous effects of this air flow are cooling of the combustion gas stream, quenching combustion reactions, and chilling of the refractory, which increases its rate of deterioration. An air-lock feeder, if space limitations permit its installation, may reduce these problems.

An air-lock-type feed would eliminate such air currents, thus reducing air pollution by noncombustible and combustible pollutants; reduce refractory maintenance and replacement frequency; and permit more control over the burning rate and the general system operation. Another important benefit is the ability to operate with more frequent addition of smaller charges, affording more stable operation. Since batch systems are, to a degree, designed to accommodate the higher than average burning rate in the period immediately after charging, semi- ⑭
continuous feed may be possible at a rate higher than the nominal rated capacity of the system. This offers an opportunity to reduce plant operating costs ($/ton) ⑮
by higher throughput.

The disadvantages of such feeders are the capital and operating costs associated with their use; the addition of another critical operation to the incineration process, which may affect system reliability; and the possibility of burn-back of refuse in the feeder (especially during burn-down). In general, however, the advantages of such a system far outweigh these disadvantages.

The estimated installation cost for ram feeders with associated hopper and hydraulic system is shown in Table K-1 below. Maintenance costs for such a system would approximate 3% of total investment (including installation) per year. The electrical and water consumption of such a system is small. Some credits may be taken from elimination of the charging gate.

TABLE K-1

ESTIMATED COSTS OF HYDRAULIC RAM-TYPE FEED SYSTEM ⑤

Furnace Capacity (TPD)	Purchased Equipment Cost	Rough Estimate Installation Cost	Estimated Annual Cost ($/yr)
50	$10,000	$25,000	$5,000
75	$15,000	$30,000	$7,000
150	$20,000	$40,000	$9,000

Note: Estimates based on mid-1969 dollars for construction in the Boston area. Costs may be 25-100% greater than those shown if major crane support or building modifications are required. Specific engineering studies are required.

Cure 2: Reduce furnace draft during charging ⑤ ⑭ ⑮

The in-rush of air accompanying the opening of the charging door can be minimized if furnace draft is reduced during charging. Caution *must* be exercised, however, as the high-temperature gases in the furnace may tend to flow through the charging gate or out of stoking doors when the furnace draft still registers below atmospheric pressure. The flows result from the "stack effect" provided by the hot gases in the furnace and small but important pressure differences in the various parts of the incinerator buildings. Consistent with this limitation, however, a decrease in furnace draft will reduce the amount and velocity of air entering the furnace during charging.

Cure 3: Avoid overfilling furnace ⑭

In some cases the charging of large quantities of refuse brings the top of the ⑮
burning bed near to the furnace outlet flue. In such cases dry papers, often unburned, may be carried out of the chamber. The "blackbirds," or large pieces of material, may pass through the subsequent combustion chambers and be discharged from the stack. Overfilling of the furnace usually reflects an acceptance of improper operating practices by the plant superintendent or an unrealistic burning schedule.

During Steady Operation

- Cause 2: Excessive underfire air (total or localized) suspending particulate ②

The noncombustile particulate emissions increase as the underfire air rate (cfm/sq ft) increases. The mechanism and importance of this interaction between ③ operating practices and emissions are discussed in Section V-B of the report on the causes of incinerator air pollution.

Cure 1: Reduce underfire air velocity (cfm/sq ft), general and localized ③ ⑭ ② ⑧

In many plants, the underfire air windbox is equipped with partitions permitting variation of the underfire air plenum pressure along the grate. Too many times, this useful and effective tool for control of underfire air quantities is not used as a direct means to reduce particulate emissions. In many plants, the underfire air dampers for the individual windboxes are left either wide open or are all opened to the same setting. It is generally recognized, however, that the feed and discharge grate areas should receive smaller quantities of underfire air than ⑧ the burning and drying grate regions. Air flow rates used should also reflect the *function of undergrate air flow in grate cooling. Specific changes should be* discussed with the grate manufacturer.

The adjustment of undergrate air, where practiced, is usually made on the basis of plenum pressures. Particularly in systems using grates with a large percentage open area (low pressure drop), undergrate pressure may be a poor measure of air flow; a substantial fraction of the pressure drop which controls flow rate occurs across the refuse bed. As a result, the variable characteristics of the refuse bed control air volume (and particulate emissions). An ideal instrumentation and control system would include both pressure and air flow sensing. The air flow rate would be the controlling parameter. Falling plenum pressure at constant air flow would indicate uncovered grate area or "blow holes." Since "blow holes" distort the even condition of underfire air flow and may cause accelerated grate damage, an alarm system sensitive to their appearance would be helpful in reducing grate maintenance and establishing good combustion condi- ⑭ tions throughout the entire refuse bed. Experimental studies of the sensitivity effectiveness of such instrumentation and control systems has yet to be carried out.

Cure 2: Replace missing or damaged grate sections ⑧ ⑯ ⑯

Cure 3: Stoke manually to cover "blow-holes"

Localized high undergrate underfire air velocities occur in regions where rapidly burning refuse components or mechanical causes lead to the exposure of the grate. In the "blow hole" region, undergrate air flow increases at the sacrifice of flow throughout the rest of the grate served from the same windbox plenum chamber. This may result in increased particulate pick-up and damage to the grate. Because of the unpredictability of such "blow holes," only an alert operator and the opportunity for manual stoking can assure a rapid return to uniform operating conditions.

- Cause 3: Impingement of overfire air jets on refuse bed ④

Cure 1: Modify to change location or direction of overfire air jets ④ ⑥ ⑤

Although overfire air jets are seldom, if ever, intentionally directed at the refuse bed, impingement of overfire air from the sidewalls may occur when the jet orifices become partially blocked with slag accumulation. This problem, known as "bearding," may often be eliminated by construction of a "peaked roof" shaped slag deflector, using brick or castable refractory, above the jet orifice. Alternatively, a small fraction of the jet air flow can be deflected up along the wall to "freeze" the slag at a safe distance above the jet orifice. Both methods have been proven in practice. ⑥

Cure 2: Reduce overfire air velocity ④ ⑥ ⑮

Until such time as modifications suggested under cure 1 may be effected or in cases where inadvertent design error has led to overfire air jet impingement on the refuse bed, the suspension of particulate matter may be reduced by decreasing the overfire air jet velocity (windbox pressure). The jet throw (penetration) is proportional to the square root of the windbox pressure; sensitive control is possible. By this means, the jet can be prevented from hitting the refuse bed. It should be recognized, however, that the quantity of air also varies as the square root of pressure, such that the total overfire air quantity and mixing effectiveness will decrease proportionately with the decreased penetration.

- **Cause 4:** CFM rating of APC device exceeded ⑮ ⑤

In most incinerator plants, the volumetric flow rate of flue gas (cfm) is excessive, in comparison to the theoretical minimum, for obtaining acceptable furnace temperatures. The effects of such excess flow rates on APC devices and performance are discussed below. ⑮

1. The efficiency of expansion chambers and electrostatic precipitators, which inherently depend for their efficiency on residence time (APC system volume divided by the volume flow rate), will decrease at high gas flows not only because of the decrease in residence time, but also because of the enhanced reentrainment of collected particulate by high ② gas velocities. For example, an electrostatic precipitator designed for operation to give 99% efficiency at 150% excess air (flue gases assumed ③ cooled by water evaporation to 600°F) would show a drop in efficiency to 97.3% (almost a three-fold increase in emission) in shifting from 150% to 250% excess air. The effects of high volume flow on emissions ④ from expansion chambers should be detectable but small.

2. The effectiveness of particulate removal in systems depending for APC ⑤ efficiency upon pressure drop (scrubbers and cyclones), will improve as the gas flow rate increases. If the pressure drop increase exceeds the ⑥ capacity of present induced or natural draft systems, however, it may be necessary to by-pass all or a portion of the untreated flue gases directly to the stack; this is unacceptable from an air pollution standpoint. In shifting from 150% to 250% excess air, for example, the pressure drop across a cyclone or scrubber system would increase more than 60%.

3. In cases where communities are considering upgrading air pollution control devices, excessive flue gas rates require the installation of oversized equipment; increasing both capital and operating costs of proposed systems and thus discouraging APC improvement. Systems designed for 250 and 350% excess air, for example, cost 15-20% more, respectively, than the equivalent design at 150% excess air. ⑪

An evaluation of plant operating practices to determine present excess air levels is straightforward. Using an Orsat apparatus, one can measure the carbon dioxide or oxygen content of the flue gases. If one assumes the average refuse composition defined in Chapter IV as representative, Figure C-1 of Appendix C can be used to determine the percent excess air. A rough estimate of percent excess air may also be obtained from measurements of the flue gas temperature (prior to evaporation of externally supplied water) by use of the temperature ⑭ scale also presented on the graph. In determinations based on either flue gas temperature or composition, considerable care should be exercised in assuring that the temperature or gas composition measured is representative of the average ⑮ in the entire flue gas flow stream.

Cure 1: Decrease refuse feed rate and corresponding air rate ② ③ ④ ⑤ ⑥ ⑪ ⑭ ⑮

Poor performance of APC devices may reflect refuse firing rates (and thus gas flow rates) exceeding the design capacity of the APC system. Reduction in refuse feed rate and a corresponding decrease in the combustion air used will obviously reduce the flue gas volume. In general, this approach is unacceptable as the consequent reduction in plant throughput and increase in cost/ton burned is impractical. Installing new or additional APC systems to match the increased gas flow, therefore, must be considered.

Cure 2: Decrease total air rate ⑤ ⑮

In many incinerator furnaces, substantial quantities of excess combustion air are used to maintain combustion chamber temperatures within limits acceptable from the standpoint of slag formation and refractory deterioration. In most plants, this air is ineffectively used. If, for example, it is desired to maintain temperatures below 1800°, only 125% excess air is necessary (based on a refuse heating value of 4400 Btu/lb higher heating value) to stay below this temperature. This calculation is based on the assumption that the flue gas within the system was perfectly mixed. While mixing of this intensity is not expected, the utilization of 200-300% excess air may not be warranted. ⑤

Increased turbulence within the combustion chamber can be realized with the use of effective overfire air jets. Additional research is required to improve the ability to predict overfire air jet effectiveness and performance, but empirically derived design methods are presented in the discussion under symptom A-3 below.

Alternative methods of wall cooling which have been successfully used to minimize the requirement for high excess air levels include air- or water-cooled refractory (especially high-quality silicon carbide or alumina), waterwall construction, or the use of air or steam jets along the wall. It should be noted that water cooling does not necessarily mean steam generation. Water-cooled metal tubes, protected by high thermal conductivity rammed refractory, can be used for sidewall construction near the grate line. Water circulated through these tubes (without steam formation) may be cooled using a cooling tower and then recycled; used for residue quenching; used for flue gas tempering; or used in wet APC systems.

The cost for such modifications varies widely, depending upon the furnace size and construction and the scope of the needed changes. The range of costs would run from $20 to $200 per TPD of capacity. The effectiveness of such changes is difficult to predict without direct analysis of the specific plant problem. ⑮

Cure 3: Seal furnace to minimize air infiltration

Many methods of sealing a refractory furnace against the infiltration of air are available. Some reduction in air infiltration can be readily accomplished by reducing the draft throughout the furnace enclosure. It is unnecessary to maintain furnace draft in excess of that needed to prevent discharge of flame or hot gases from the furnace during operation. Such a draft only serves to increase the quantity of air drawn into the furnace through cracks in refractory, firing doors, air ports, and the like. An equivalent concept would use an automatic draft control on the induced draft fan.

Minimizing air infiltration can also be accomplished by instituting standard operating procedures requiring that all furnace doors, viewports, and the like, which are unnecessary for operation be kept closed. The importance of this simple precaution is suggested by the fact that a 2-foot square door opening into a furnace, at a draft of 0.25 inch of water, would pass all the combustion air required for a 30-TPD incinerator operating at 150% excess air. ⑤

In some furnaces, substantial amounts of tramp air are admitted through cracked refractory walls and roofs. These problems are particularly important with suspended wall and roof construction. In these circumstances, castable, inorganic sealants can be applied to caulk the system. Alternatively, a light gauge steel or aluminum enclosure can be constructed about the furnace. Consideration should be given to insulating the steel to avoid condensation on the inner surface which can lead to rapid corrosion.

Cure 4: Shift to water sprays instead of air dilution for
flue gas cooling (if applicable) ⑤⑬⑮

In some incinerators, air dilution is used to temper flue gas temperatures to avoid damage to induced draft fans or APC equipment. Although such air tempering systems are inexpensive to construct and operate, the flue gas volume is substantially increased in the process. Appendix B discusses the merits and costs of alternatives in flue gas conditioning and should be used as a reference to evaluate alternatives. ⑬

- Cause 5: APC device ineffective ⑮

Cure 1: See Criterion III, Reliability, Symptom 2, Cause 5

Cure 2: Seal dust outlet valves (cyclones)

The collection efficiency of cyclone dust collectors is reduced substantially if air infiltration occurs through the dust outlet valves. Such tramp air, passing up through the mass of collected particulate, readily re-suspends the ash and moves it into the exit gas flow. Although most cyclones are equipped with special dust valves to avoid this problem, improper maintenance, corrosion, or the build-up of hard ash deposits may prohibit complete closure and air inleakage will occur. These valves should be inspected and cleaned frequently and, as they have a great impact on cyclone efficiency, must be replaced when necessary.

Cure 3: Upgrade APC device

In most cases, high particulate loadings in the stack gas reflects an inefficient air pollution control device. Although improved operating practices can make a minor improvement in stack emission, by far the most effective method involves installation of an efficient air pollution control device. In the section of this report dealing with the alternatives in air pollution control systems for incinerators, the anticipated efficiency, selection methodology and costs are presented in some detail. (See Section VII-B.)

During Cleaning of Boiler Tubes

- Cause 6: APC system unable to cope with short-term, high-particulate loading

  Cure 1: Clean more frequently to avoid peaks in particulate loading when cleaning boiler tubes

  Cure 2: Consider modifications in cleaning methods or timing to reduce resuspension of fly ash when cleaning boiler tubes

  Cure 3: Consider modification in APC equipment to increase capacity

Symptom A2: Excessive Emission of Noncombustible Gaseous Pollutants (NO_x, SO_2, HCl)

The mechanism of formation of noncombustible gaseous pollutants is discussed in some detail in sections V-F and -G; each deals with the nature and causes of incinerator air pollution. The reader should review these sections to assist him in understanding the operation of his own plant and the justification for the causes and cures shown below.

- Cause 1: APC devices ineffective for these pollutants ①

Dry APC systems will not collect noncombustible gaseous pollutants. The collection efficiency of wet APC systems is negligible for nitrogen oxides, usually small for sulfur oxides, but may be as high as 100% for hydrogen chloride. The efficiency variation depends on the relative solubility of these pollutants in the scrubber water and the adequacy of contact between the flue gas and water. The importance of these pollutants is not presently considered critical for incineration. When industrial refuse containing large quantities of sulfur or halogen-containing materials comprises a substantial fraction of the incinerator input, however, consideration should be given to upgrading the collection efficiency for these pollutants.

Cure: Install or redesign system to accommodate devices of greater efficiency, if warranted ① ⑬

As described above, collection efficiency is related to both pollutant solubility and the adequacy of contact between the flue gas and the absorbing medium. If control of these pollutants becomes important, dry collectors must be abandoned or supplemented by wet collection devices. The efficiency of wet devices for collecting gaseous pollutants can be increased by two methods: (a) maintaining an alkaline water-wash to increase the solubility of the acidic gases (SO_2 and HCl) and (b) using a scrubber with high contacting efficiency.

Water alkalinity may be readily produced by adding soda ash. An added benefit of such treatment is the decrease in corrosion rate. Untreated scrubber water normally becomes acid (pH values as low as 1.5 have been reported) after only one or two cycles, thus rapidly degrading both basic refractory and carbon steel surfaces. Soda ash treatment systems have been used in a large number of incinerators, particularly where recycle of the scrubber water is practiced. Based on our assumed average refuse composition, the soda ash requirements for neutralization of HCl and SO_2 approximates $0.04 per ton of refuse at 1969 bulk soda ash prices. For a 250-TPD plant, the annual cost for soda ash would range between $1500 and $3000 per year, depending upon usage. ⑬

Improved contacting efficiency between the flue gas and the water may be accomplished in the following ways:

- Increasing the number of spray heads and water quantity used;
- Increasing the average residence time (chamber volume divided by flue gas volume flow rate) within the contacting device or spray chamber;

- Installing additional baffles consistent with pressure drop limitations, and assuring their complete flooding with water.

- Operating a multistage countercurrent flow scrubbing device

③ The improvement in adequacy of contact has secondary benefits in that increased removal of particulate material should also be effected. ④

- Cause 2: Concentrated influx of sulfur and/or halogen-containing refuse materials

  Cure 1: Inspection of refuse and refusal of such materials ⑨ ⑥

Municipal incinerators also servicing industrial plants are often confronted with substantial concentrations of halogen and sulfur-bearing refuse materials. Undoubtedly the incineration of such materials will produce unacceptably high stack concentrations of sulfur or halogen-containing pollutants. Thus it may be appropriate to institute controls over the refuse delivered, or even to refuse such materials. (See Criterion III – Reliability, symptom 5, cause A-2, cure 5.)

  Cure 2: Mix such materials in the pit to reduce peak emission levels ⑨ ⑨

- Cause 3: NO_x generation in high-temperature regions

⑪ Little data identifying the locations within an incinerator where nitrogen oxide generation occurs are existent. As a broad generalization, however, nitrogen oxide formation is favored by high temperatures and high excess air. Although the quantitative effects are unknown, it is reasonable to expect that maintaining ⑫ uniform and lower flue gas temperatures throughout the incinerator will reduce nitrogen oxide emissions. However, refuse incineration typically represents a small source of nitrogen oxides within a community. Hence, implementation of the cures shown below should probably be considered as a side benefit to solving other incinerator problems rather than ends in themselves. ⑭

  Cure 1: Cool locally by better utilization of forced air (mixing) ④ ⑥ ⑭

  Cure 2: Reduce underfire air to avoid intense hot spots in refuse bed ③ ⑪ ④

  Cure 3: Improve stoking to break up hot spots ⑫

Symptom A3: Excessive Emission of Combustibles (including smoke, Carbon Monoxide, Hydrocarbons and Carbon)

The mechanism of formation and destruction of combustible pollutants is discussed in detail in sections V-B and V-C. The reader should review those sections as an aid in understanding the operation of his plant and the justification for the causes and cures shown below.

During Start-up ④

- Cause 1: Insufficient gas temperatures because of excessive quantities of air in relation to the heat release rate.

During start-up of an incinerator, the combustion air supply often greatly exceeds the demand. As a result, the pyrolysis products rising from the refuse bed ⑥ are rapidly cooled, leading to the formation of combustible pollutants, such as smoke, carbon dioxide, polynuclear hydrocarbons, and the like. Since there are no other sources of heat within the system, these pollutants persist and, barring collection in an air pollution control device, will be discharged from the stack. Control methodology, as a result, deals with the modulation of combustion air during start-up and the use of initial refuse charges which readily burn without the formation of smoke (dry refuse). ⑨

Cure 1: Control air supply to the system to avoid quenching combustion ④ ⑥ ⑭

During the start-up period, the overfire air should be minimized as the relatively small heat liberation within the furnace is easily overwhelmed by the overfire air flow rate typical of steady operation. The rate at which the overfire air jets are brought on-stream depends on the incinerator type and the refuse being burned. More important than any mechanical devices in controlling this problem is a staff of operators who are interested and concerned about reducing heavy smoke emission during start-up.

Cure 2: Select initial refuse charges that are readily combustible ⑨ ⑭

Cure 3: Use auxiliary oil (#1 or #2 grades) or gas-fired burners

To bring the incinerator up to a temperature approaching that of steady operation, auxiliary firing of either gas or light oil could be used. In most situations, oil firing would be preferable as the greater luminosity of the oil flame would provide for more rapid warming of the furnace chamber and more efficient use of the combustion energy. If it is assumed that oil-firing is used, a 240-TPD incinerator, which is fired during the first hour of operation in the week at a firing rate equivalent to half of the average heat release rate corresponding to steady operation, would incur an annual operating cost approximating $1250 per year (approximately $0.02 per ton of refuse incinerated). The investment cost for oil storage, pump, burner, and fan systems would approximate $10-$15,000 for plants with one or more units of this size.

Benefits of combustion chamber preheating undoubtedly exist. It is probably true, however, that the cost for auxiliary heating during start-up or shutdown would be unacceptable, particularly in light of the efficacy of good start-up practices on reduction of smoke emissions. ④ ⑤

Cure 4: Bring unit up slowly

During Charging ⑥

- Cause 2: Quantities of cold air entering combustion chamber through charging gate, reducing flue gas temperature

Cure 1: Convert batch feed to continuous or air-lock-type feed system (See symptom A1, cause 1) ⑤ ⑭ ⑮

Cure 2: Auxiliary fire combustion chamber during charge period

Auxiliary firing during charging is practiced in only a few small installations. In one plant where data are available, the average energy consumption was 500,000 Btu's/ton of refuse burned. Even with low-cost fuels, this adds $0.25 to $0.50 per ton to the cost of incineration. If possible, therefore, alternative methods, such as going to an air-lock-type feed system, are preferable.

- Cause 3: Excessive quantities of refuse are charged to the furnace in relation to the supply of air

Cure 1: Use smaller weight per charge ④ ⑥ ⑭ ⑭

When a fresh charge of dry refuse enters the hot furnace, there is a rapid evolution of combustible pyrolysis products. In most cases, the combustion air system is unable to cope with such a large amount of combustible and the result is smoking and the formation of carbon monoxide and hydrocarbons. In a number of controlled tests, the peak concentrations of combustible pollutants in the stack flue gases was shown to be correlated directly with the time of charging. The severity of these combustible pollutant peaks can be reduced significantly by ⑮ smaller charges. The problems of tramp air infiltration through the charging gate should be considered, however, and on the assumption that an air-lock-type feed system is not available or installed, a compromise between batch size and charging frequency should be established by experiment.

Cure 2: Reduce or shut off underfire air during charging
(batch systems) ③ ⑭ ③

The rate of evolution of combustible pyrolysis products from the refuse bed is strongly related to the underfire air rate. It is helpful, therefore, to reduce underfire air during the time of charging. Overfire air should not be reduced, however.

Cure 3: Moisten refuse to reduce pyrolysis rate ⑨ ⑬ ⑭

The evolution of combustible pyrolysis products does not generally begin until the refuse has been dried. As a result, moistening (not soaking) refuse offers a means of controlling the duration and rate of the pyrolysis portion of the refuse incineration process.

Moistening of refuse at the time of its delivery to the pit will also assist in minimizing dusting during mixing and charging operations and will act to temper the combustion temperature in the primary furnace. ⑨ By decreasing the ultimate flame temperature of the refuse, moistening will allow use of less excess air in the combustion chamber in order to stay within the safe operating limits of the refractory. (See Table B in Appendix B for the effect of water addition on maximum flame temperature.)

In some municipalities, a sharp decrease in average refuse moisture and an increase in refuse heating value, primarily due to the increased use of domestic garbage disposal systems, have been noted in recent years. The resulting increase in flame temperatures within the incinerator has required a decrease in the system burning rate in order to avoid overheating. Moistening of the refuse to temper ⑬ combustion temperatures would, in effect, restore a large portion of the "lost capacity" by replacing the cooling effect of air dilution (which places great ⑭ demands upon the forced and induced draft equipment) with water evaporation and water vapor heating.

During Steady Operation

- Cause 4: Inadequate mixing of air and partially burned flue gases

As described in section V-C, stimulation of mixing in the overfire volume provides the greatest opportunity for reduction in emissions.

Cure 1: Installation or redesign of overfire air jets for more efficient gas mixing ④ ⑥ ⑭

Overfire air jets provide a convenient and controllable method for stimulation of turbulence in the overfire volume. These devices have been installed in most new incinerators and have been used for over 50 years in association with the burning of bituminous coal. Although overfire air jets are used primarily to eliminate smoke, they also have proven advantageous in reducing slag accumulation and in reducing the overall air requirement within the system. ④

Unfortunately, few controlled experiments have been carried out to show the quantitative effects of overfire jets or to provide principles for design and layout in incinerator applications. Recent work (supported by the Bureau of Solid Waste Management) at the Oceanside Refuse Disposal Plant, Oceanside, Long Island, New York, has provided an empirical equation for overfire air jet penetration (or throw).[4,5] ⑥ The (dimensional) equations, based on flow of *cold* air into a *cold* furnace, are as follows:

$$\text{Air flow rate (cfm)} = 1096.5\ CA\sqrt{(P_1 - P_2)/W}$$

in which

C = flow coefficient of 0.9 (tapered inlet);

A = the nozzle cross sectional area in square feet;

$(P_1 - P_2)$ = the difference in pressure between the furnace and overfire air manifold (inches of water column);

W = density of air at the nozzle temperature and pressure in units of pounds per cubic feet

The equation developed for calculating jet throw is:

$$\text{Throw} = 0.75D\ \sqrt{(P_1 - P_2)}$$ ⑭

for which:

Throw = the distance in feet from the nozzle orifice to the point where the centerline jet velocity has dropped to 1500 feet per minute;

D = nozzle diameter in inches;

$(P_1 - P_2)$ = pressure differential (as described above).

This study suggested that a damper be provided for each nozzle when the static pressure cannot be adjusted adequately by dampers in the supply manifold. Utilization of these jets (which were mounted about 2 feet above the refuse bed along the entire length of the furnace) was shown to "reduce the color of the stack plume to a light haze."

As mentioned above, however, these design equations are preliminary and further engineering evaluation and testing are required to provide general design principles useful for improving existing plants and providing improved designs for new plant construction.

Cure 2: Installation of baffles or other turbulence generators ⑥ ⑮ ⑤

Cure 3: Lower flue gas discharge point ⑥ ⑥

In most incinerators, the inefficient mixing of the gases over the fuel bed is readily apparent; the hot, fuel-rich luminous gases rise from the refuse bed directly to the furnace roof. Cooler gases pass out along the bottom of the outlet flues. This stratification of flue gas temperature and composition may be readily studied using a hand-held thermocouple probe. Not only does one typically find that the temperature varies greatly in the vertical direction across the outlet flues, but gas analysis shows substantially greater combustible content in the hot portion of the flue gas stream.[46] It has been suggested that to improve the mixing of these hot and cold gas streams, the outlet point for the furnace should be lowered. Little experimentation has been carried out to evaluate quantitatively the impact of this suggested modification, but with the use of air-cooled bridge walls, such modifications are possible.

- Cause 5: Inadequate residence time of flue gases

Analysis of the rates of combustion reactions (see sections V-C and -D) shows clearly that for gaseous pollutants, such as carbon monoxide and hydrocarbons, the reaction times required for their complete destruction in well-mixed systems is of the order of thousandths of a second. The combustible portion of the particulate matter (essentially carbon) and some of the condensed, high molecular-weight hydrocarbons require longer (but not excessive) times for burnout. The cures described below suggest means for increasing the time available for ⑮ the burn-out of these materials. High flue gas temperatures and vigorous mixing, however, are better solutions in most cases.

Cure 1: Install secondary chamber ⑤

Based on an average of data taken from 45 U.S. plants of a variety of different capacities and types, the mean residence time of the flue gases in the primary chamber is 2 seconds (calculated as the ratio of the primary chamber volume to the volumetric flow rate of gases at the exit temperature of the primary – see Table B-1, Appendix B, for methods used to estimate this latter quantity). The comparable quantity for the primary plus secondary chamber volumes is 6 seconds. To assess the need for additional combustion volume, this value (6 seconds) is a useful benchmark. It should be noted that this value exceeds by a factor of 2 or 3 the residence time found satisfactory in smaller, on-site incinerators. This difference indicates the need, effect, and difficulty of obtaining sufficient mixing in large incineration units. The method of calculating mean residence time is discussed below.

Referring again to Table B of Appendix B, one finds the unit flue gas volume (cfm/TPD) corresponding to a given operation under the column for zero excess water evaporation. This value is then substituted into the following equation:

Average residence time (seconds) = 60V/cfm

where

V = total volume of primary and secondary chambers, including flues, where temperatures exceed 1200°F

cfm = unit flue gas volume (see above) multiplied by the plant capacity (TPD).

This equation must be modified if only a fraction of the secondary chamber is suitable for combustion due to the cooling action of water sprays. The only volume included in this calculation should be that which is hot enough (above 1200°F) to support vigorous combustion (see cure 3 below).

If necessary, additional chamber volume may be installed on an existing plant. This would represent a major modification to the furnace, and, as a result, the cost of accomplishing this addition would be difficult to assess without specific knowledge of the plant site, space available, and so forth. If such a modification should be indicated, detailed engineering evaluation would have to be carried out. It should be noted, however, that a time of 5 to 6 seconds may not be required: the intensity and uniformity of mixing may well be the controlling parameters. The high cost of adding additional combustion volume, therefore, suggests that alternatives be considered first.

Cure 2: Reduce refuse feed rate (see cause 4, cure 1) ② ⑪

Cure 3: Modify system to increase residence time.

② In many incinerators, the flue gases are subjected to the cooling effects of water sprays or wetted baffles immediately upon exiting from the primary chamber. The rapid cooling of the gases to temperatures below 1100-1200°F effectively stops the combustion reactions. Unless it is necessary to cool flue gas streams at this point in the furnace, additional residence time can be obtained by moving the point where quenching sprays are introduced to a location further downstream. The equation and evaluation methodology described under cure 1 can be applied to determine the time increment which would be gained by such modifications. Checker walls should be considered to assist in holding temperature.

If decisions to implement this cure are made, consideration should be given to the adequacy of the refractory brick or other materials of construction in the region now protected by the cooling effect of water evaporation. Also, the ability of the structure to expand and contract with temperature changes should be evaluated.

- Cause 6: Inadequate functioning of APC devices by congestion with particulate ⑨

  Cure: See Criterion III – Reliability, symptom 2

- Cause 7: Cfm rating of APC device exceeded ⑪

  Cure: See symptom 1

- Cause 8: Refuse feed too dry ⑨

When dry refuse is fed to a continuous-flow incinerator, the evolution of pyrolysis products from the refuse bed occurs primarily on the initial few feet of the grate. Under such conditions, the combustion air supply may be inadequate and, as a result, carbon particles (soot) and high molecular weight hydrocarbons (tars) are formed. The high temperature of this gas volume leads to stratification of the flue gases, making subsequent mixing and burn-out more difficult. It is, therefore, advantageous to extend the length of grate over which the pyrolysis occurs. The cures listed below address themselves to means of accomplishing this.

Cure 1: Mix refuse in pit to blend wet and dry refuse ⑨ ⑩

Cure 2: Decrease underfire air on feed grate; increase overfire air at the feed end ③ ④ ⑥ ⑭

Decreasing the underfire air has the effect of slowing the burning rate within the bed and consequently reducing the rate of generation of pyrolysis products. Relative to the overfire air, many incinerators are constructed with the overfire air jets distributed evenly along the grate. The primary need for overfire air mixing, however, is in the first one-half to (at most) two-thirds of the furnace. Overfire air is of little use over the last third of the grate where residue burn-out occurs. Presently installed overfire air fan capacity may be utilized more effectively, therefore, by installation of increased numbers of jets in the sidewall adjacent to the feed and ignition grate areas and dampering down or shutting off the jets over the discharge grate. ③ ④ ⑤ ⑥

- Cause 9: Excessive air rates which lower the flue gas temperatures

Cure 1: Reduce combustion air rate ③ ④

Cure 2: Seal furnace to minimize infiltration (see cause 4, cure 3) ⑤ ⑮ ⑨

Cure 3: Increase refuse feed rate ⑪

Symptom A4: Inadequate Dispersal of Stack Gases ⑩

Incinerators which meet the most stringent air pollution control emission standards may still have flue gases containing undesirable materials; e.g., fine particulate and some noxious or suffocating gases. It is necessary, therefore, to assure that the stack gases are well dispersed and diluted by atmospheric air. The effectiveness of this dispersion is related to a number of parameters. For the case of a stack located at some distance from buildings or other obstructions, dispersion (as characterized by the ground-level concentrations downwind) is closely related to the exit velocity of flue gases and their temperature. When buildings (including the incinerator itself) are nearby, or when the land area is irregular, a number of other factors must be taken into account. For *preliminary* evaluation of relatively *simple* problems, booklets such as the "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents,"* or "Workbook of Atmospheric Dispersion Estimates,"** are useful. ⑪ ⑭ ⑮

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*Available from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York 10017.

**PHS Publication No. 999-AP-26, available from the U.S. Dept. of Health, Education and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio.

From the standpoint of dispersion the stack height may be broken into two parts: the actual stack height representing the height of the physical stack above the terrain; and the equivalent stack height increment, which takes into account the plume rise due to the exit velocity and the flue gas temperature (buoyancy). Because of the variable effectiveness of the three methods of improving stack gas dispersion in different situations, no definitive discussion of the cures below is given. Instead the reader is directed to evaluation media such as the guides mentioned above. ②

- Cause 1: Insufficient stack height or equivalent

    Cure 1: Increase height of stack ⑮

    Cure 2: Maximize flue gas stack temperatures for buoyancy ⑮

    Cure 3: Increase stack gas exit velocity ⑮

- Cause 2: Unfavorable meteorology

    Cure 1: Shut down ②

    Cure 2: Operate to minimize emissions ⑨

Symptom A5: Dusting of Refuse In Pit

Cure 1: Moisten refuse ⑨ ⑬

Cure 2: Draw combustion air from tipping floor area (see Criterion III – Reliability, symptom 2, cause 4)

Symptom A6: Dusting of Residue at Disposal Site

Cure 1: Moisten residue ⑬

Cure 2: Use soil cover promptly

Cure 3: Compact residue ⑮

Cure 4: Add dust settling aids (e.g., calcium chloride)

Symptom A7: Odors Emanating from Refuse Pit ①

- Cause: Excessive refuse residence time
  - Cure 1: Empty pit frequently ⑩
  - Cure 2: Use masking odorants
  - Cure 3: Provide adequate pit drainage ①
  - Cure 4: Frequent pit cleaning ①
  - Cure 5: Draw combustion air from tipping floor area (see Criterion III – Reliability, symptom 2, cause 4)

Symptom A8: Odors from Stack

- Cure: See causes and cures for gaseous and combustible pollutants

Symptom A9: Odors Emanating from Settling Pond

- Cause 1: Presence of putrescible in residue; combustible in fly ash
  - Cure: See Criterion II – Residue Quality ⑩
- Cause 2: Pond operating under anaerobic conditions
  - Cure: Make at least the surface aerobic (spray ponds, surface aerators, etc.)

Symptom A10: Odors Emanating from Residue Disposal Site

- Cause 1: Poor residue quality
  - Cure: See Criterion II – Residue Quality
- Cause 2: Anaerobic decay in residue
  - Cure 1: Improve residue quality
  - Cure 2: Maintain site drainage

Cure 3: Operate site as a sanitary landfill (cover residue) ①

- Cause 3: Fires in residue disposal site

Cure: See Criterion II – Residue Quality

Symptom A11: Odors Emanating from Residue Trucks

- Cause 1: Poor residue quality

Cure 1: See Criterion II – Residue Quality

Cure 2: Wash and sanitize trucks frequently ①

Symptom A12: Exhaust Emissions of Delivery and Residue Trucks

Cure 1: Establish and enforce vehicle emission performance codes for collection and residue vehicles

Cure 2: Maintain plant vehicles to minimize emissions

Cure 3: Schedule deliveries to minimize the number of trucks operating at the incinerator at any one time.

B. WATER POLLUTION RESULTING FROM SEEPAGE OR DISCHARGE OF INADEQUATELY TREATED LIQUIDS

Symptom B1: From Refuse Pit

- Cause 1: Seepage through cracks in pit floor

Cure: Repair leaks and seal surface

- Cause 2: Liquids from pit discharged without proper treatment

Cure 1: Connect to sanitary sewer (if compatible with municipal standards)

Cure 2: Pump to settling pond

Cure 3: Pump to residue quench tank

Cure 4: Use pit sump liquids to moisten refuse

Symptom B2: From Residue Quench Water

- Cause: Water leaking or expelled from system not treated or directed to a settling pond

  Cure: Seal system and direct water to a settling pond

Symptom B3: From Flue Gas Conditioning System or APC Device

- Causes and Cures: See symptom B2

Symptom B4: From Settling Pond

- Cause 1: Inadequately designed settling pond, allowing liquids to penetrate the ground and pollute surrounding ground water

  Cure: Seal pond with asphalt, bentonite, kaolin, etc.

- Cause 2: Inadequate disposal program for pond dredgings

  Cure: Transfer solids immediately to residue site and cover

- Cause 3: Lack of, or inadequate treatment of, pond liquids

  Cure 1: Increase pond average residence time

  Cure 2: Develop aerobic conditions with sprays or surface aerators to increase BOD reduction capability

Symptom B5: From Residue Disposal Site

- Cause 1: Drainage of quench and rain water from disposal site

  Cure: See Criterion II – Residue Quality

- Cause 2: Inadequate landfill hydrology

  Cure 1: Cover and seal landfill

  Cure 2: Ensure proper run-off and drainage

  Cure 3: Change disposal site

Symptom B6: From Wash-down Waters

See symptom B1

C. AESTHETICS

Symptom C1: Shoddy Appearance of Site and Mobile Equipment

The problems of obtaining adequate funds to operate and maintain an incinerator are due in part to the poor public image offered by many incinerator plants. In distributing plant operating costs among the various cost centers, it is appropriate that the majority of the funds be expended in connection with the incinerator furnaces and materials handling equipment. It is improper, however, to disregard the effect of shoddy plant appearance on public apathy and employee motivation, or to accept degradation of the living space surrounding the plant as a necessity.

Cure 1: Include general housekeeping and facilities upkeep practices for the mobile equipment, incinerator building, and adjacent plant property in the maintenance and operating program

Cure 2: Eliminate or minimize refuse blowing away from pit and refuse accumulation in excess of pit storage capacity, as indicated below

Cure 3: Minimize littering of incinerator property by collection vehicles

Cure 4: Require closed or covered refuse hauling vehicles

Symptom C2: Refuse Blowing Away from Pit During Dumping

- Cause 1: Lack of or inadequate windbreak around pit

  Cure 1: Improve or install windbreak

  Cure 2: Enclose tipping floor

- Cause 2: Prevailing wind directed towards entranceway and/or exit of pit enclosure

  Cure 1: Install and use automatic or manually operated power doors for entrance and exit

Cure 2: Install a windbreak to shield the doorway

- Cause 3: Poor delivery practices

  Cure: Enforce dumping practices which minimize spillage, require clean-up, or provide housekeeping services

- Cause 4: Poor housekeeping practices

- Cause 5: Improper design of tipping area structures

  Cure: Install proper curb (including sweepways)

Symptom C3: Refuse Accumulating in Excess of Pit Storage Capacity

- Cause 1: Pit inadequately sized for the delivery rate to the incinerator

  Cure 1: Enlarge pit ⑩

  Cure 2: Reschedule refuse collections, deliveries, or incinerator operating schedules

  Cure 3: Provide a sanitary temporary holding site ⑩

- Cause 2: Incinerator operating below design capacity

  Cure 1: See Criterion III – Reliability – and Criterion V – Cost

  Cure 2: See cures for cause 1

- Cause 3: Refuse delivery rate to incinerator site exceeds rated capacity of unit

  Cures: The construction of additional incineration capacity or institution of other modes of refuse disposal, such as sanitary landfill, refuse hauling, and so forth

Symptom C4: Spillage of Refuse During Handling and Feeding

- Cause 1: Poor operating and maintenance practices with crane

  Cure 1: Review operating practices to minimize spillage consistent with crane operation

  Cure 2: Improve maintenance to assure closure of bucket

- Cause 2: Inadequate design of the refuse feed hopper

  Cure: Replace or modify the existing hopper

Symptom C5: Noise

- Cause 1: Fans

  Cure 1: Incorporate regular inspection program to maintain fans in balance

  Cure 2: Modify the fan inlet, housing, and damper assembly to minimize projected noise

- Cause 2: Refuse handling equipment

  Cure 1: Enclose pit area

  Cure 2: Maintain crane regularly

  Cure 3: Install less noisy crane drive mechanisms

  Cure 4: Modify operating practices to avoid impacting bucket against pit walls

  Cure 5: Install rubber bumpers on walls

  Cure 6: Install noise abatement materials and structures for refuse shredding equipment

- Cause 3: Noise from trucks

  Cure 1: Require adequate mufflers on engine exhaust and modified hydraulic pumps for collection vehicles

Cure 2: Consider using embankments or other sound reflectors, absorbents, or baffles around tipping area

Symptom C6: Odor

Cures: See section A – Air Pollution – above

Symptom C7: Heavy Traffic

- Cause: Poor collection and delivery scheduling

  Cure: Modify collection schedules to spread out the traffic to and from the incinerator site more uniformly

Symptom C8: Vermin

- Causes and cures are discussed in section D, below

Symptom C9: Plume Visibility

- Cause 1: Smoke from stack

  Cure: Plume opacity or smoke (other than steam plumes) is due largely to the fine particulate passed by the APC devices or aerosols which are formed subsequent to the APC system by the condensation of hydrocarbon tars. The combustible contribution to plume opacity can be dealt with as described above under combustible pollutants. There is little that can be done, other than improving APC efficiency, to minimize opacity due to uncollected, noncombustible particulate. The contribution to plume opacity from condensing water vapor is discussed below.

- Cause 2: Steam Plume

In many cases, an otherwise acceptable incinerator stack appears unacceptable because of the condensation of water vapor to yield a dense plume. Although harmless, such a plume attracts attention and complaints from nearby residents. The color of the plume is variable, depending upon the illumination and the background.

In cool weather, the moisture content of the refuse itself is often sufficient to cause a steam plume. Under normal circumstances, this will not occur in summer. When wet scrubbers or evaporative flue gas tempering methods are used, however, steam plumes will form under almost any weather condition, particularly when the flue gas is saturated. ② A steam plume will form whenever a gas stream is cooled below its saturation temperature or dew point. Although the flue gases rising from an incinerator stack are cooled to some extent by radiation, the primary cooling mechanism is mixing with ambient air. A discussion of this process and the methods for prediction and control may be found in Appendix B.

Cure 1: Modify design or operation of flue gas conditioning system to avoid condensation of steam resulting in visible plume ⑬

Cure 2: Consider reheat of flue gases ② ⑬

Cure 3: Consider dry APC system ⑬

D. HEALTH HAZARDS DUE TO BREEDING OF DISEASE VECTORS

Symptom D1: At Refuse Pit

Cure 1: Modify feeding to incinerator unit to assure minimal residence time of refuse in pit ⑨ ⑩ ⑨

⑩ To minimize the population of flies and other insects in the pit area, it is helpful to turn over the pit inventory rapidly. By this means, the insects are destroyed in the larval or pupal stage. Although the pit is never completely emptied in many plants, the crane operator should be instructed to assure that little or no refuse remains in the pit longer than one to two days. This practice has been shown to be effective in a number of plants throughout the country.

Cure 2: Clean out pit regularly ⑬

Cure 3: Use insect and rodent control measures in pit area

Symptom D2: At Residue Disposal Site

- Causes: The presence of putrescible material on residue

Cure 1: See Criterion II – Residue Quality

Cure 2: Institute insect and rodent control measures

Cure 3: Cover residue regularly

Symptom D3: At Settling Pond

- Cause 1: The presence of putrescible material in the water serviced at the settling pond

  Cure 1: See Criterion II — Residue Quality

  Cure 2: Institute insect and rodent control measures

- Cause 2: The accumulation of dredged solids near the pond site

  Cure: This material should be compacted and covered at the residue site immediately

CRITERION II: POOR RESIDUE QUALITY

ALL SYMPTOMS

- Cause 1: Inadequate residence time in combustion chamber ②

An effective but costly method for the improvement of residue burn-out is ③
to increase the residence time of refuse within the combustion chamber of continuous-feed units by decreasing the grate speed or by allowing longer burn-down times in batch feed units. In most municipalities, decreasing the production ④
rate in the incinerator is unacceptable. As a consequence, initial consideration should be given to alternate methods of burn-out improvement. ⑤

Cure 1: Decrease grate speed (be cautious not to allow bed height to exceed critical level) ② ⑧ ⑪ ⑫ ⑥

Cure 2: Allow more time before dumping grates (for batch incinerators) ② ⑪

- Cause 2: Inadequate temperatures in refuse bed and furnace ⑧

Cure 1: Increase supply of underfire air to dry the refuse (on feeding, batch systems, or under feed grate, continuous systems) and force burning on the grate. Decrease undergrate air on burn-down (batch) or on discharge grate (continuous) ③ ⑧ ⑪ ⑭

Cure 2: Increase supply of refuse to the chamber if, in fact, feeding system is starving the primary ⑪
chamber ② ⑤ ⑫

Cure 3: Auxiliary firing ②

Because of the high cost of auxiliary fuel, this alternative is economically unfeasible for most applications. Under some conditions, as when firing extremely wet refuse, some auxiliary firing may be justified although alternate methods ⑭
(such as mixing in the pit to increase average refuse heat content) are highly desirable. Use of auxiliary firing has practical significance in only a few circumstances, such as pathological or sewage sludge incinerators.

Cure 4: Decrease overfire air ④ ⑤ ⑥ ⑭

Decrease of overfire air should be evaluated carefully. When the refuse bed temperatures are low, the quantity of volatile combustion products increases, thus increasing the combustion load in the overfire furnace volume. Under these circumstances, overfire air quantities may have to be increased and consideration given to stimulation of high turbulence.

Cure 5: Install reflecting arch ②

- Cause 3: Inadequate supply and/or distribution of underfire air-limiting combustion ③

Cure 1: Increase underfire air by increasing underfire air fan capacity or pressure ② ③ ⑮

Cure 2: Improve distribution of underfire air (less to discharge and more air to ignition/burning zones) ③ ⑭

The control of underfire air is important relative to several of the criteria of incinerator performance. In many modern plants, existing underfire air dampers are not regularly used as a means to control combustion conditions. In other plants, the underfire grate air dampers or windbox partitions have fallen into disrepair or are nonexistent. The use of such a powerful tool to control incinerator operation should not be overlooked. With such equipment, however, appropriate instrumentation should be provided (preferably air flow-sensing equipment, but at least undergrate plenum pressure gauges). ⑦

- Cause 4: Inadequate stoking of refuse bed to expose fresh surface

Cure 1: Modification of stoking mechanism operation to improve mixing ⑫ ⑭

For some systems (particularly those with reciprocating or rocking grates) it may be possible to modify the frequency and stoke of the grate members to improve mixing, while maintaining adequate refuse residence times. Discussions of the effects of such modifications should be taken up with the grate manufacturer, particularly in relation to increased maintenance. ⑫

Cure 2: Incorporation of preventive maintenance program to assure the proper operation of the stoking mechanism ⑫ ⑭ ⑮

Cure 3: Manual stoking ⑦ ⑫

Manual stoking of the refuse bed is often used to break up clumps of papers and the like. The increasing number of aerosol cans and other rapid burning, explosive, or dangerous refuse components demands caution and required use of protective equipment by the operators. As a minimum, such equipment should include heavy gloves, a full face shield, and safety glasses.

Cure 4: Utilize crane and bucket to mix and loosen refuse in pit prior to charging ②

- Cause 5: Slugs of wet material entering furnace

Cure 1: Mix refuse in pit ⑨ ⑭

Cure 2: Manual stoking (see cause 4, cure 3 above) ⑦ ⑫

Cure 3: Allow longer dwell time in pit to assist moisture dispersion ⑨ ⑩ ⑭

An analysis of the moisture content of various refuse components taken from storage bins shows that a substantial redistribution of moisture among refuse components has taken place. ⑦ This process has been exploited by increasing the holding time of refuse in the pit prior to charging.

- Cause 6: Feed with thick cross section

Cure 1: Remove such items from feed – do not accept at ⑨ the plant and give proper instructions to crane operator ⑨ ⑩

Cure 2: Size reduction ② ⑨

To operate an incinerator at an acceptable rate, materials of thick cross-section usually experience a residence time insufficient for complete combustion. Limited size reduction can be accomplished by the operators of the crane and by ⑫ individuals on the charging floor. Such operations might include unrolling carpets and the use of the bucket tines to abuse rolls of newsprint or other large baled material. In plants receiving large amounts of such bulky waste, a special facility for size reduction utilizing hammermills or other attrition equipment may be appropriate. ⑭ The estimated costs for such equipment are shown in Appendix A of this report.

CRITERION III: POOR RELIABILITY (Excessive, Unscheduled Downtime)

Symptom 1: Equipment Failure

- Cause 1: Inadequate, improper, or negligent preventive maintenance program

The institution of industrial maintenance practices for a municipal incinerator is certainly justified by the magnitude of the investment and the importance of continued operation to the health and welfare of the community. In general, dollars expended in maintenance are repaid many times over in increased equipment availability and life and in reduced expenses for major repairs. It is obviously unfeasible for this report to discuss the detailed preventive maintenance needs of the variety of incineration systems across our country. The following needs, however, are suggested:

1. Review historical plant records to isolate problem areas for intensive maintenance;
2. Contact equipment vendors for recommended maintenance procedures and frequency;
3. Review operating practices, in comparison with the original design basis of the system and its components, with the consulting engineers and vendors to assess the need for more comprehensive or frequent maintenance;
4. Analyze the economic effects of down-time (including labor, capital, overtime premium, additional disposal costs, etc.) to justify increased maintenance appropriations;
5. Consider contract maintenance for instruments, controls, or other special equipment;
6. Increase the effectiveness of the maintenance crew by assigning some maintenance functions to the operators;
7. Use signed checklists and frequent inspections to assure that the work is done.

- Cause 2: Poor Operating Practices

The problem of poor operating practices pervades much of the incineration industry. Because of the large number of systems involved, it is unrealistic to attempt to discuss specific problems for all incinerator plants. In many cases, the poor practices arise from insufficient training by the manufacturer or component vendors. In other cases, poor operating practices have developed over the years from attempts to minimize the effort required of the operators. Some plants, for example, operate with all the combustion air fans "wide open" to avoid problems in slagging and refractory overheating. While such practices may meet the objectives described, they may be entirely inappropriate for attaining effective air pollution control in the plant. Similarly, many plants are operating far above the design capacity, thus overloading the air pollution control device, producing low quality residue, and stressing the equipment to the detriment of plant reliability.

To pinpoint poor operating practices, individuals who are well informed on plant practices should be interviewed by those who understand the operating needs of the system and its components. Once these inefficient practices have been identified, some of the cures suggested below may be of use in maintaining operating practices at an acceptable level.

Cure 1: Institute formal training programs upon employment; also hold refresher courses at regularly scheduled periods, perhaps annually; also regularly scheduled studies of equipment operating characteristics, maintenance needs and methods, public health, safety, and the like, should be undertaken by operating personnel

Cure 2: Prepare manuals, standard operating procedures, and so forth, and require that these procedures be implemented

Cure 3: Modify operator and/or supervisor qualifications and job descriptions to fit needs

Cure 4: Conduct inspections and testing to evaluate performance

- Cause 3: Inadequate Design

The specification of cures for systems or components which are inadequately designed is obviously too comprehensive a task to be included in this study. Such an analysis and the preparation of recommendations should be conducted by competent engineers who are familiar with the equipment in question. It is clear, however, that many incinerators are being operated under conditions far different from those comprising the design basis. This difference may reflect inadvertent design errors, subsequent changes in refuse composition, changes in plant requirements, or changes in operating practices. Some general solutions to such problems are:

1. Modification of operating practices to minimize the effect of the design deficiencies; ②
2. Intensification of maintenance efforts to compensate for the design deficiencies; or
3. Modification or replacement of the defective components as appropriate.

Selection of which solution or combination of solutions is most reasonable may require some experimentation and will definitely need detailed engineering evaluation. In most cases, however, the results of such efforts are justifiable. For a typical 400-TPD incinerator, for example, the losses in fixed cost and labor charges for a single day's outage results in a minimum loss of $1500.

Symptom 2: Congestion or Plugging of Gas Passages

- Cause 1: In batch-charged systems raw refuse is blown into the breeching because of excessive overflow of refuse and/or high gas velocities in the primary chamber

  Cure 1: Regular clean-out can minimize or prevent draft loss

  Cure 2: Install draft gauges to anticipate problems ⑪

  Cure 3: Burn down refuse and dump grates more frequently ② ⑪

- Cause 2: Excessive siftings accumulation resulting in blockage of underfire air wind-box

  Cure 1: More frequent siftings removal ⑯

  Cure 2: Siftings removal inspection ⑯

- Cause 3: Fly ash accumulation in flues ⑯

  Cure 1: Design to reduce horizontal surfaces (use hopper bottoms)

Cure 2: Regular clean-out procedures ①

Cure 3: Minimize fly ash evolution by modification of operating procedures (see Criterion I – Environmental Pollution – symptoms A1, A3)

Cure 4: Sluice chamber bottoms ①

The problem of fly ash accumulation in flues and secondary combustion chambers has often been moderated or solved by the use of water sluicing. In some cases, water sprays are used. Unless the primary chamber has been especially designed for high turbulence, however, most of the secondary chamber volume is needed to ensure adequate burn-out of combustible gases and particulates. Few, if any, existing plants meet this turbulence criterion. For this reason, wet-bottom combustion chamber designs are acceptable, but the use of water sprays should be avoided. Such sprays rapidly cool the combustion gas, thus stopping the combustion reactions short of completion. Where the sluice water is recirculated, unusually, severe problems of chemical corrosion and mechanical abrasion of fly ash-bearing water should be anticipated in the design of the equipment and in the selection of materials of construction. Materials such as fiberglass reinforced polyester, rubber-lined pumps, and acid proof refractory are acceptable. Chloride attack upon some of the stainless steels should be evaluated if such material is used.

- Cause 4: Plugging of ducts drawing combustion air from tipping zone

In many cases, it is desirable to draw combustion air from the tipping zone. When the tipping area is enclosed, the dust levels can become high, thus increasing crane maintenance costs and frequency of failure and producing an undesirable working environment. Often, the ducts, fans, and grillwork associated with tipping area exhausters become plugged with loose papers and dust. In several plants, in fact, the system has been eventually abandoned. Because of the many advantageous features features of using this source of combustion air, efforts should be made to keep this portion of the incineration system operable.

Cure 1: Regular clean-out of ducts and intake grills (design for accessibility)

Cure 2: Use dust collection equipment (e.g., self-cleaning screens) before fan

- Cause 5: Plugging of air pollution control devices (or ash hoppers)

Congestion of air pollution control devices either because of the accumulation of particulate matter within the devices themselves or plugging of the hoppers holding the collected ash can seriously affect plant reliability. Also, such ② blockages may require by-passing the air pollution control device by opening relief dampers or else cause a severe degradation of the system's collection ③ efficiency, both of which would increase environmental pollution.

Cure 1: Regular clean-out (design for accessibility)

Cure 2: Modify or replace existing APC devices

In some cases, APC systems may be modified to reduce their tendency to plug. Such problems are primarily associated with scrubbers and small-diameter ⑥ cyclone systems. Small diameter cyclones are prone to plugging when the fly ash is tar-laden or when moisture droplets are carried over from the flue gas conditioning system. In some cases, water sluicing using hand-held lances or fixed, coarse water sprays may be useful for intermittent clean-out. Such an installation would be relatively inexpensive. Consideration would have to be given, however, to the effects on the subsequent fly ash handling system, especially as regards corrosion or caking of cement-like fly ash in hoppers, outlet valves, and the like.

Modifications to tray-type scrubbers may also be necessary if heavy fly ash loadings result in tray blockage. Higher water rates, lower recycle to make-up water ratios, larger downcomers, modified water inlet nozzles, or improved waste-water clarification may assist in maintaining free flow through the plate. Any such changes should be discussed with the equipment vendor and subjected ⑪ to careful engineering scrutiny.

If it is decided that the existing equipment is unable to function adequately (section VII-B), the cost and effectiveness of air pollution control devices should be reviewed in relation to anticipated effectiveness and comparative cost estimates of alternatives.

Cure 3: Cut back on underfire air, reducing particulate ⑭
carry-over (see Criterion I – Environmental Pollution – symptom A1) ③ ⑪ ②

Cure 4: Complete combustion of tars, etc., to avoid caking of particulates (see Criterion I – Environmental Pollution – symptom A3) ⑭ ⑥

Cure 5: Elimination of water droplet carry-over from water spray flue gas conditioning system to prevent caking (13)

Incinerator fly ash will readily adhere to moist surfaces, resulting in the rapid build-up of hard cement-like deposits. Incinerators using water sprays to cool or condition the flue gas stream prior to an otherwise dry air pollution control device are thus subject to severe problems if the water droplets are not entirely evaporated at the point of entry into the dry collector. The completeness of evaporation is dependent on a number of variables, including the initial water droplet size distribution, the initial flue gas dry bulk temperature, and the evenness of distribution of the water droplets throughout the flue gas stream. As a result, definitive predictions of required evaporation time following the last spray are difficult to compute. In a well mixed system, however, preliminary estimates of evaporation time may be obtained from the technical source referenced below.* It should be noted, however, that calculated evaporation times based upon this paper will be shorter than the actual time needed to assure dry flue gas and particulate. Obviously some degree of conservatism should be provided to account for uncertainties in flow patterns, spray characteristics, etc.

Such analyses, however, clearly show the advantages of small initial droplet sizes. Such fine sprays require high-pressure pumps and filtration systems to assure continued operation without plugging. Such a system should include suitable controls to modify the water flow rate to maintain a constant outlet temperature, alarms in case the pump fails, and a spare pump in case of such failure. The capital and operating costs for this equipment are presented in Appendix B which concerns itself with flue gas conditioning systems.

Cure 6: Elimination of condensation to prevent caking (13)

As described under cure 5, incinerator fly ash will build up at points where dampness exists within the air pollution control device. One common cause of such dampness is the condensation of water vapor from the high-moisture-content flue gas on cool surfaces in the ash hopper or in areas of low gas velocity (corners, etc.), in the air pollution control system housing. These problems may be seasonal, being more important and widespread in the winter when the outdoor temperatures are low. The majority of these problems can be averted by application of insulation. Such insulation costs are generally small and can probably be provided for in the annual maintenance budget. If insulation is required over large (13) areas, an estimated cost of \$3 per square foot (materials and labor – 1969 dollars – Boston area) can be assumed for preliminary budgeting purposes.

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*Duffie, J.A., and Marshall, Jr., W.R., Chem. Engineering Progress, 49 (8), 1953, pp. 417-423.

Cure 7: Installation and/or maintenance of cleaning devices

Cure 8: Avoid discharge of fly ash in high-moisture regions

As described above under cure 6, attention should be given to high moisture regions throughout the entirety of the fly ash handling system. In a number of instances, fly ash outlet pipes discharging several feet above the sluicing trough have experienced problems when steam rising from the trough condensed at the outlet point of the tube. ④

Symptom 3: Slag Build-up Interfering With Grate Operation ⑥

- Cause 1: Excessive Temperature of Walls Adjacent to Grate

Cure 1: Cool walls by increasing the heat removal through the wall adjacent to the grate. This may be accomplished by:

– Replacing fireclay refractory with air-cooled, high thermal conductivity refractory

– Installation of water-cooled metal walls (boiler tubes, etc.)

– Steam or air sparging along the wall. ④ ⑬ ⑥

- Cause 2: Excessive temperature of airborne solid particulates which fuse to the wall ⑬

Cure: Steam or air sparging in the zone adjacent to wall ④ ⑬ ⑥

- Cause 3: Infrequent slag removal

Cure: Incorporation of a regular cleaning program

Symptom 4: Failure of Utilities

- Cause 1: Water or power failure outside plant limits

  Cure: Install emergency power and water systems if warranted

- Cause 2: Inadequate preventive maintenance programs for water and electrical equipment and controls

  Cure: Incorporation of such a preventive maintenance program

- Cause 3: Improper operation of electrical and water equipment resulting in equipment damage

  Cure 1: Establish and follow proper operating procedures ⑦

  Cure 2: Install alarms and interlocks ⑦ ⑧

  Cure 3: Institute training programs (see symptom 1, cause 2) ⑦

- Cause 4: Inadequate design to cope with emergency situations

  Cure 1: Install:

  - Emergency relief stack with vent with action independent of utility service; ⑦
  - Emergency power supply ⑦

  Cure 2: Inspect, test, and maintain emergency systems

Symptom 5: Hazardous Occurrences

a. Burning under grates

- Cause A1: Inadequate maintenance of grates resulting in excessive accumulation of combustible siftings ⑯

  Cure 1: Promptly replace damaged grates ⑧ ⑯

Cure 2: Incorporate preventive maintenance and grate inspection program ⑧ ⑯ ①

Cure 3: Review siftings removal practices (more frequent removal) ⑯

- Cause A2: Refuse components such as molten aluminum, paint, plastic, or grease contributing to undergrate burning

Cure 1: Install viewing port and use it regularly ⑧ ⑯

Cure 2: Install flame-sensing devices and alarms ⑦ ⑧ ⑯

Cure 3: Install fine water sprays to extinguish fires ⑧ ⑯

Cure 4: Install adequate fire hose ① ⑧ ⑯

Cure 5: Inspect incoming refuse to avoid introduction of large quantities of these materials ⑨ ⑯ ⑦

Certain incinerator air pollution, maintenance, and operating problems are ⑧ caused by feeding large amounts of problem refuse materials over a short time period. Such materials include fusible plastics, large quantities of combustible ⑨ liquids, large chunks of wood, aluminum turnings, and rubber. The effect of feeding large quantities of these materials on incinerator operation can be simply a short-term nuisance or a disaster. Fortunately, such occurrences are infrequent. In some locations, however (particularly near industrial waste sources), such problems may be common.

One way to cope with such problems is through close specification of acceptable and unacceptable refuse materials, including provision for substantial fines or other penalties for the offending industries and/or hauling contractors. Alertness on the part of the weigh master or the crane operator can often avert such problems, and often the problems can be eliminated or substantially reduced by mixing in the pit.

Another solution involves the designation of one of the operators, or an individual especially hired, to serve as an inspector. This latter course is too costly in most situations, but may be appropriate when large, high-pressure boiler equipment is being used such that the importance of fixed costs, loss of by-product credits, and risks to personnel in the case of equipment failure are ⑯ substantially increased. The cost of such surveillance in terms of dollars per ton of refuse processed depends largely upon the plant size and utilization. Estimates of this cost may be obtained by referring to the operating costs developed in the section of this report dealing with concepts based on existing technology (section VII-D).

In addition to mixing in the pit to reduce the effects of undesirable refuse feed, occasions will arise when material removal is appropriate. For such circumstances and to permit pit cleaning, provision should be made for discharging material from the pit to an area in front of the pit or outside the building. This can be accomplished by extension of the bridge crane travel beyond one end of the pit or by the installation of a discharge chute. The chute should be designed for storage out of the way when it is not in use.

b. Refuse pit fires ⑤

- Cause B1: Carelessness, i.e., cigarette butts, matches, etc., thrown into pit

  Cure 1: Rigidly enforce safety procedures near pit ⑦ ⑦

  Cure 2: Install fire-fighting and fire-sensing equipment ⑦

- Cause B2: Lack of restrictions on materials entering pit, such as live coals, hot loads ⑨

  Cure: Institute and enforce restrictions on incoming refuse (see symptom 5, cause 2) ⑨ ⑩

- Cause B3: Spontaneous combustion

  Cure: Limit residence time of refuse in pit ⑩

c. Smoking from primary chamber

- Cause C1: Plugging of gas passages

  Cure: See cures for symptom 2

- Cause C2: Inadequate draft ⑮

  Cure 1: Consider shift to induced draft ⑮ ⑤

  Cure 2: Increase ID fan capacity ⑮ ⑤

Cure 3: Modify system to permit control of ID fan speed ⑭ ⑮ ⑤

Cure 4: Reduce feeding rate and forced air supply ② ③ ④ ⑤ ⑥ ⑪

Cure 5: Avoid draft upsets by utilizing air seals (see Criterion I – Environmental Pollution – symptom A1, causes 1.4) ⑤ ⑭

d. Feed chute fires

- Cause D1: Poor design

  Cure 1: Modify the design to increase the ratio of length-to-width cross-sectional area

  Cure 2: Seal furnace to increase furnace draft (see Criterion I – Environmental Pollution – symptom A1, causes 1.4) ⑤ ⑭

- Cause D2: Poor charging operation resulting in inadequate seal

  Cure 1: Improve charging procedures to maintain constant seal of the feed chute (keep the chute full)

  Cure 2: Avoid charging oversize by inspection of refuse and by making provision for removal of oversize from pit (see symptom 5, cause A2) ⑨

Symptom 6: Inadequate Spare Parts Inventory

- Cause 1: Poor management, supervision, or inadequate budget

  Cure: Review plant records and manufacturer's recommendations and maintain adequate spare parts inventory, anticipating needs; justify by emphasizing high cost of unscheduled outages

- Cause 2: Poor design (lack of spares for critical auxiliaries)

  Cure: Install spare or shared-load twin pumps, fans, etc., if justified

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Symptom 7: Labor Problems

The problems of labor relations are beyond the scope of this report. However, establishment of better lines of communication between labor and supervision, giving the plant supervisor the right to hire and fire personnel, providing adequate sanitary and locker-room facilities, and attending to plant morale are vital, but often disregarded, management principles.

Symptom 8: Governmental or Judicial Actions (injunctions)

- Cause 1: Failure to meet applicable air and water pollution, health, or misdemeanor (public nuisance) codes

  Cure: See Criterion I – Environmental Pollution

CRITERION IV: SAFETY CONSIDERATIONS

EMPLOYEE INJURIES

Symptom 1: Unsafe Practices

As mentioned under Criterion III – Reliability – it is not possible in a report such as this to address the problem of unsafe plant operating practices in detail. Usually such practices reflect unfavorably upon the plant supervisory staff, although often the motivation for such practices is the desire to keep the plant ④ running and to accomplish its mission rather than willful negligence. In many of the sophisticated plants under construction today which incorporate high-pressure ⑤ boiler systems, the potential for major accidents will be ever-present. In these plants, a new sense of the importance of employee safety is needed. Continuance of many of the compromises reflected in the operation and maintenance of existing plants could soon result in human tragedy.

- Cause 1: Lack or poor enforcement of general policies concerning proper operating practices and use of safety equipment such as hard hats, face shields, safety glasses, and protective gloves and clothing
    - Cure 1: Adoption and rigid enforcement of such safety policy
    - Cure 2: Safety training
    - Cure 3: Safety promotion

Symptom 2: Objects Expelled from Primary Combustion Chamber

- Cause 1: Lack of, or improperly designed, doors and shields to prevent objects from being expelled from primary chamber
    - Cure: Proper design and installation of such doors
- Cause 2: Leaving the doors open
    - Cure 1: Close the doors if not required to admit combustion air ⑤
    - Cure 2: Install overfire air system ④

In a number of older plants, the stoking doors in the primary furnace are left open intentionally to admit combustion air. In modern plants, this practice may reflect an inadequate design of the combustion air supply system. In older plants air deficiencies may also reflect changes in the composition of refuse such that increased air flows are needed to maintain acceptable furnace temperatures. An effect equivalent to such tempering air can be obtained by moistening the refuse (see Criterion I, symptom A-3, cure 3) or a supplementary overfire air system can be installed. The design of such an overfire air system should be discussed with the furnace or grate manufacturer. It is not envisioned, however, that the capital or operating costs of such a system would be great.

Symptom 3: Burns and Smoke Inhalation

- Cause 1: Surfaces normally contacted in operation of units that are too hot

  Cure 1: Insulation of chamber walls

  Cure 2: Install (and/or maintain) air-cooled walls

  Cure 3: Install expanded metal or other off-set protective barriers

⑨

- Cause 2: Sudden discharge of flame or hot gases from chambers during charging due to rapid release of heat in furnace

  Cure 1: Use smaller charges ⑪

⑪

  Cure 2: Consider moistening refuse ⑨ ⑬

  Cure 3: Avoid charging highly combustible or explosive materials ⑨

⑬

  Cure 4: Equalize pressures between charging floor and furnace floor (fans, hopper, design)

- Cause 3: Inadequate charging floor ventilation

- Cause 4: Inadequate egress for crane operators

Symptom 4: Falls

- Cause 1: Inadequate guard-rails and similar protection

Cure: Evaluate facility needs for fall-prevention barriers

- Cause 2: Poor placement of equipment for maintenance

  Cure: Consider relocation of equipment or installation of properly designed ladders, catwalks, and railings to allow safe maintenance of poorly located equipment

- Cause 3: Slippery floors, steps, and platforms

  Cure: Apply anti-skid coatings, stair treads, etc.

Symptom 5: Equipment

- Cause 1: Unsafe equipment and plant design

  Cure 1: Install safety devices (belt guards, shields, relief valves, etc.) and maintain them

  Cure 2: Modify operating procedures for maintenance scheduling to avoid hazardous conditions

  Cure 3: Consider modification or replacement of hazardous equipment

- Cause 2: Unsafe plant operation

Symptom 6: Fires

- Cause 1: The improper storage, handling, and accumulation of combustibles

  Cure 1: See Criterion III – Reliability (Hazardous Occurrences)

  Cure 2: Institute periodic fire safety inspections of the incinerator site

- Cause 2: Dump fires

  Cure 1: Inhibit formation of marsh gas by compacting the residue and assuring the proper residue site drainage

Cure 2: Minimize combustible in residue (see residue quality) and quench adequately

- Cause 3: Pit fires

Cure: See Criterion III – Reliability (Hazardous Occurrences)

Symptom 7: Dust Inhalation

- Cause: Excessive dusting of refuse and residue

Cure: See Air Pollution

Symptom 8: Accidents to Employees and Trespassers in the Residue Disposal Site

- Cause: Lack of enforcement of adequate safety procedures for employees and inadequate signs and fences to dissuade trespassers from entering residue disposal area

Cure: Institution of same

CRITERION V: EXCESSIVE COSTS PER TON FOR INCINERATION AND RESIDUE DISPOSAL

Symptom 1: Burning Less Than Planned Annual Capacity

- Cause 1: Excessive down-time ③

  Cure: See Criterion III – Reliability

- Cause 2: Changes in refuse composition (Btu content, bulk density) ④

  Cure 1: Consider modification of air and flue gas handling systems (flues and breechings, forced draft fan systems, overfire air openings, APC systems, induced draft fans, stack); made necessary by increased combustion air requirement for high Btu refuse ⑮ ③ ④

  Cure 2: Consider moistening refuse (see Criterion I, symptom A-1, cause 3, cure 3) ⑨ ⑬

  Cure 3: Consider addition of larger crane bucket (decreased bulk density) ⑨

- Cause 3: Plant operating practices limit throughput

  Cure: Review operating practices and plant goals (capacity vs. residue quality)

Symptom 2: High Maintenance Costs per Ton of Refuse Processed

- Cause 1: Operation of equipment in excess of design capacity ⑬

  Cure: Review current operating practices in context of design basis

- Cause 2: Lack of preventive maintenance ⑮

  Cure: See Criterion III – Reliability

- Cause 3: Corrosion of metal parts

  Cure 1: Treat scrubber water (see Criterion I, symptom A-2, cause 1)

Cure 2: Protective coatings on wet surfaces in contact with flue gases ①

Cure 3: Review of design requirements and replacement with more durable materials

Cure 4: Maintain surface temperatures above dew point (insulation, heating) ⑬ ⑨

Cure 5: Consider redesign of portions of the system ④

- Cause 4: Spalling, slagging, fluxing, and cracking of refractory

Cure 1: See Criterion III – Reliability

Cure 2: Avoidance of rapid temperature changes ⑭

Cure 3: Consider installation of materials with improved characteristics

Cure 4: Consider alternatives in wall cooling ④

- Cause 5: Erosion ⑨

Cure 1: Consider shift to erosion-resistent materials of construction

Cure 2: Consider installation of box elbows (for pneumatically transported fly ash or fly ash slurries)

Cure 3: Install wear surfaces

Symptom 3: Excessive Utilities Consumption per Ton of Refuse Processed ⑬

- Cause 1: Excessive cost of residue quench water ⑭

Cure 1: Drill well or use pond water for process applications ①

Cure 2: Clarify, treat, and recycle water (clarifiers, lagoon) ①

Cure 3: Modify system to minimize water carry-over from quench tank ①

Cure 4: Consider modification to dry ash handling system

- Cause 2: Excessive water cost for flue gas cooling

  Cure 1: Use finer sprays (approach total evaporation)

  Cure 2: Clarify, treat, and recycle water

  Cure 3: Install automatic water control system sensitive to flue gas temperature

- Cause 3: Excessive electrical costs

  Cure 1: Pinpoint major users and consider alternate operating practices

  Cure 2: Consider automatic inlet vane dampers or variable rpm for induced draft fan ⑮

  Cure 3: Consider automatic ID fan control, sensing furnace chamber pressure ⑭

  Cure 4: Evaluate pressure drops in flue gas and air supply ducting and modify duct configuration or clean out ducts as appropriate

Symptom 4: Excessive Labor Costs per Ton of Refuse Processed

- Cause 1: Inefficient use of labor

  Cure 1: Review operating practices to improve planning of assignments

  Cure 2: Review labor requirements and evaluate installation of automatic equipment ⑭

  Cure 3: Review supervisory activity and strengthen, if necessary ⑮

  Cure 4: Institute employee training to improve capabilities

  Cure 5: Evaluate employee qualifications versus system requirements

- Cause 2: Overstaffing

  Cure 1: Consider reduction in staff consistent with safety, maintenance, operating effectiveness, and employee relations

  Cure 2: Consider expansion of plant responsibilities to disperse labor costs

- Cause 3: Inadequate employee motivation

  Cure: Institute practices and policy to stimulate employee job satisfaction and retain trained personnel

It is beyond the scope of this report to address the problem of improving employee job satisfaction. It is a well-known principle of management, however, that plants will operate more effectively and economically in a working environment where the employees can take pride in their work and in themselves. Although certain approaches to these objectives are useful, the following are suggested. Employees should be encouraged to wear street clothing when coming to work and should be provided uniforms; high-grade locker and shower room facilities should be provided and maintained; the role of the Sanitation Department in maintaining public health should be clearly explained during training sessions; achievement and suggestion box awards should be provided for employees' contributions which significantly improve plant performance, air pollution, public relations, and so forth. The impact of such management practices on plant performance is difficult to determine. Historically, however, the return on these and similar modest investments in human relations has proven more than satisfactory.

Symptom 5: High Residue Disposal Cost

- Cause 1: Excessive residue volume and weight

  Cure 1: Operate to obtain maximum weight and volume reduction (see Criterion III – Residue Quality)

  Cure 2: Consider mechanical reduction of residue to reduce volume

  Cure 3: Consider residue fusion in a subsequent or separate unit operation

The concept of fusion or melting of incinerator residue in a separate operation is part of a number of advanced concepts now in the research or early development stage. If such processes are of interest, refer to section VII-E dealing with advanced technology relating to slagging concepts.

Cure 4: Consider by-product recovery of ferrous metal and glass (see also Appendix F)

Several plants throughout the country defray operating costs by the recovery of metal from incinerator residue. Normally, such an operation requires cleaning the residue (e.g., by using a water-washed rotating screen) followed by magnetic separation of the ferrous metals. Although the economics of such a process may appear attractive, it is well to evaluate carefully the long-term stability of steel scrap prices and markets at the anticipated scale of operation before entering into such a venture.

Recovery of glass from refuse (before incineration) may be practical in areas where stable markets can be found. At the present, however, costly hand picking is required to segregate different colored glasses, and markets are uncertain.

Cure 5: Consider dry ash handling

- Cause 2: High land costs

  Cure 1: Secure less expensive sites, recognizing cost of longer haul distances, if required

  Cure 2: Use compaction to obtain minimum residue volume

- Cause 3: Requirement for cover material

  Cure 1: Obtain high enough residue quality to minimize requirement

  Cure 2: Obtain site where cover is available

- Cause 4: Requirement for long haul distances

  Cure 1: Obtain site closer to plant

  Cure 2: Evaluate alternatives in size and type of hauling vehicles

NOTES

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A

Parameter No.	Parameter
1	Waste Water Generation
2	Plant Operating Costs (excluding debt cost)
3	Underfire Air
4	Overfire Air
5	Flue Gas Volume Flow Rate
6	Flue Gas Mixing
7	Plant Safety
8	Grate Damage
9	Refuse Composition and Properties
10	Pit Holding Time
11	Refuse Firing Rate
12	Stoking Characteristics
13	Moisture Content of Flue Gases
14	Combustion Control
15	Fan Capacity
16	Siftings Problems

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